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STRUCTURES IN THE ORDOVICIAN ROCKS OF VICTORIA

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Abstract

Microscopic, mesoscopic and macroscopic structures imposed on the Ordovician rocks of Victoria are described. Deposition and folding were pene-contemporaneous, deposition taking place in rapidly subsiding troughs. It is believed that deposition was restricted for the most part to two main troughs: the Western Trough and the Eastern Trough. The former virtually ceased to exist at the close of the Lower Ordovician; the latter began its development at that stage and was effectively destroyed at the end of the Upper Ordovician. Two tectonic axes: the Heathcote, and the Dookie-Tatong, are regarded as being of considerable significance, and a third axis, represented by the Muckleford Fault, also played a major role in the tectonic history of the Ordovician rocks.

Introduction

As a result of a series of detailed studies of structures in the Ordovician rocks of Victoria, it became apparent that both the similarities and differences in the styles and the geometry of the structural elements provided significant data for the assessment of the tectonic development of these rocks. This paper is a systematic description and analysis of the structures studied: microscopic, mesoscopic and macroscopic structures have all been considered.

Microscopic structure means one which can be seen only under the microscope and includes those elements which can be determined by petrofabric analysis alone. Mesoscopic structures are those to be observed in a single continuous exposure, or handspecimen, and include bedding, folds, foliations, lineations and joints. Macroscopic structures are those which can be determined only by the synthesis of mesoscopic data and lithological and stratigraphic mapping.

Fig. 1 shows the distribution of Ordovician rocks in Victoria. Stratigraphically and structurally, as well as geographically, the rocks fall into two units: those of eastern Victoria which are mainly of Upper Ordovician age and which, in many places, have suffered superposed deformation; the second unit comprises the Ordovician rocks of western Victoria, which are, for the most part, Lower Ordovician, and which, except very locally, have been subjected to a single folding deformation. In both far eastern and far western Victoria, the sediments have been regionally metamorphosed. The eastern metamorphic belt is the more prominent; in western Victoria the schists and gneisses are exposed only in valleys where erosion has removed younger rocks.

Due largely to the work of W. J. Harris, D. E. Thomas, and the Geological Survey of Victoria, the regional structure of the eastern sector of the Western Trough, including the form of macroscopic folds, is well known. Because of mining activity in this region the mesoscopic structural elements have also been studied in some detail, but published systematic descriptions are few (Hills & Thomas 1945; Beavis 1964). In spite of detailed mapping by J. G. Easton, in north-eastern Victoria, virtually nothing is known of the structure of this region, due largely to the apparently uniform lithology and the almost completely unfossiliferous nature of

FIG. 1—Distribution of Ordovician rocks in Victoria. This figure shows the localities mentioned in the text.

the rocks. In far western Victoria, the only publications relating to structure are those of Wells (1956) and Clappison (1960). Here, as in the eastern part of the State, macroscopic structure can often only be surmised. In 1939, D. E. Thomas described the broad structural features of the Lower Palaeozoic rocks of Victoria. Since that time, with the exception of some important papers on the structure of the Silurian rocks, little of significance has been added. Thomas (*op. cit.*) noted that the most westerly exposures of Ordovician rocks, the precise stratigraphic position of which is known, are those of Bealiba, Goldsborough, Tarnagulla, Dunolly and Maryborough. The assumed Ordovician rocks to the W. are unfossiliferous and since at the localities noted, the fossils are all Lancefieldian, the possibility that the sediments to the W. may be Cambrian cannot be excluded. In the eastern part o fthe Western Trough the structure and stratigraphy are well known except for the area NW. of the Harcourt Batholith, although the work of the Geological Survey since 1939 (as yet unpublished) may have elucidated this. S. and N. of the Harcourt Batholith the structure is known in great detail (see Fig. 2).

Harris and Thomas have described the macroscopic folds in the graptolite-bearing sediments as 'domes' and 'basins', i.e. relatively open, broad anticlinoria and synclinoria. Thomas now uses the terms 'brachyanticlinoria' and 'brachysynclinoria' which seem preferable. Within these macrofolds, the sediments are more or less sharply folded, with average dip of bedding 70° and the average distance between hinges of mesoscopic folds 250 to 300 ft. Regional reversal of plunge and the adjunction of folds with plunge in opposing directions have the effect of an anticlinorium giving way to a synclinorium, e.g. the Pyrete anticlinorium to the Woodend synclinorium, the Riddell synclinorium to the Axedale anticlinorium and the Lauriston anticlinorium to the Strathfieldsaye synclinorium. Effectively, there is an *en echelon* pattern of anticlinoria and synclinoria.

With the possibility of stratigraphic and lithological mapping outside the fossiliferous belt only slight, macroscopic structure can be only surmised. In NE. Victoria, e.g. the Kiewa Anticline has been postulated (Beavis 1962a), with evidence to suggest that while it is comparable to the anticlinoria of the Western Trough, it tends more to be a long open structure lacking the typical hinge line characteristics (i.e. reversal of plunge).

Hills and Thomas (1953) envisaged deposition in a large single basin which, in the early Ordovician, was deepest in the western half of the state, while in the eastern half, deposition did not begin until the Upper Ordovician. They considered that emergence first occurred from this basin in the E., but that the basin as a whole was not destroyed until the Mid-Devonian Tabberabberan Orogeny. Their conclusion that the effects of the Benambran and Bowning Orogenies were confined to eastern Victoria was supported by this writer (Beavis 1962a), but Hills and Thomas concluded that 'minor dislocatory movements, superimposed on the broad sinking of the trough, were operative virtually continuously, the "orogenies" being culminations of such movements'.

Large scale faulting has disrupted the Ordovician rocks; some, at least, of the faults are very ancient structures and may date from the Ordovician. Again, the faults for the most part are known only where detailed stratigraphic mapping has been possible: the faults have often been inferred from the absence of graptolite zones. Many of the more important faults are meridional, e.g. the West Kiewa Thrust, the Muckleford Fault and the Whitelaw Fault. Others, such as the Hanover, Djerriwarrh and Tawonga Faults, trend north-easterly. Only a few trend E.-W. Most of the faults are high-angle thrusts, a few are wrench faults. Later renewed

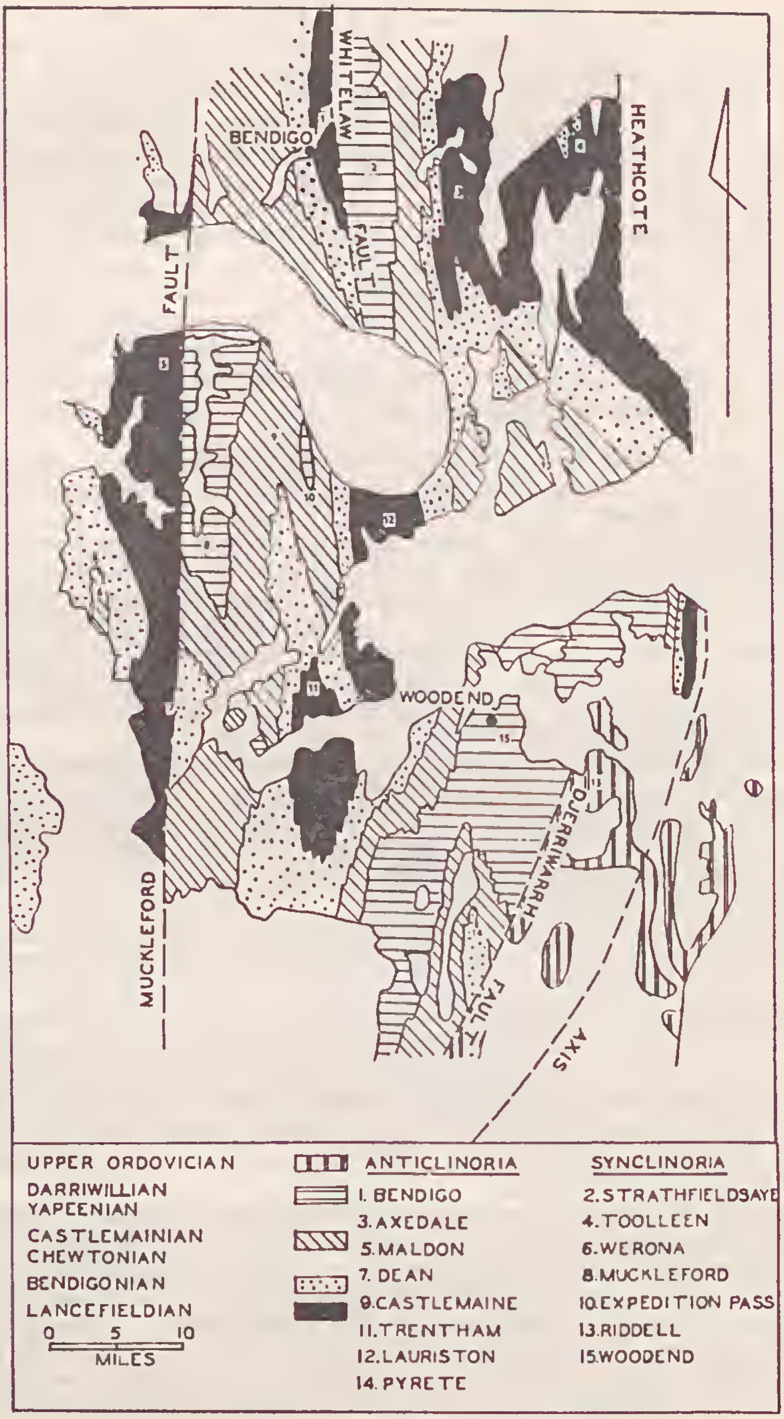

FIG. 2—Structure of the eastern sector of the Western Trough; after D. E. Thomas.

movement often differed from the original, e.g. the Tawonga Fault originated as a dextral wrench, but the late Cainozoic movement was low-angle thrusting (Beavis 1960); in Central Victoria, Cainozoic normal faulting took place along Palaeozoic high-angle thrusts. In some cases, *en echelon* fault systems occur, e.g. in North East Victoria, the Tawonga, Granite Flat, and Cudgewa Faults form such a system. The time and structural relationships of faulting and folding are sometimes clear, but are more often obscure. The relationship between folding and intrusive activity is often quite intimate. It has been shown, e.g. that cleavages and small folds have been superposed on sediments about the Harcourt and Beechworth batholiths (Beavis 1964b, 1964c), while there has been a suggestion that the macroscopic folds may have influenced the locus of batholith intrusion (Stewart 1962; Beavis 1964b). The plutons intrusive into the Ordovician rocks vary in age relative to the folding, and any influence of, or on, the folding would have been controlled by the age relationship.

A further factor which influenced the structure of the Ordovician rocks was the nature of the sediments. This is particularly true for the mesoscopic structures. Variation in composition and texture of the sediments resulted in variations in the reaction of the rocks to stresses. Throughout the state, the rocks are alternating greywackes and slates and their metamorphic equivalents. Often the beds are one to two ft thick, but relatively thick beds of greywackes and slate are not uncommon. The condition of the rocks during deformation, and their tectonic environment, were additionally of considerable importance, particularly in the development of superposed structures.

This paper describes and discusses the microscopic, mesoscopic and macroscopic structures, firstly for the western sector of the state, W. of the Heathcote Axis, and secondly for the eastern sector, E. of the Dookie-Tatong Axis. Finally the data are discussed.

In a project of this kind, many people have contributed, but special reference should be made to my wife, who carefully prepared many of the figures; to Dr D. E. Thomas, Professor E. S. Hills and Dr O. P. Singleton, who have over a period of years discussed many aspects with me, and to the late Dr W. J. Harris who first introduced me to many of the fascinating problems of Ordovician geology in this state.

The Ordovician Rocks West of the Heathcote Axis

Microscopic Structures

With the exception of the coarse greywackes, the crystalline schists and rare quartzites, the Ordovician rocks in Victoria do not lend themselves readily to petrofabric studies and few such analyses have been made. Quartz and mica sub-fabrics of the crystalline Casterton Schists were described by Wells (1956), quartz subfabrics of greywackes in the Chewton district by the writer (Beavis 1964b). Usually the mica fabrics show the micas lying in two *s* planes: bedding, and foliation (aB). Symmetry is near monoclinic to triclinic. The quartz fabrics have a symmetry from near orthorhombic, to monoclinic or triclinic. The actual relationship of quartz orientation to mesoscopic fabrics is not always clear, and lacking detail given by axial distribution analyses, the main value of the quartz fabrics lies in their symmetry.

Dimensional orientation of quartz grains in quartzites, sufficient to impart a foliation to these rocks, is rare. It is seen, however, in some cleaved greywackes. Any such dimensional orientation is visible only microscopically: the rarity of this structure suggests that the deforming stresses were not sufficiently strong or that the confining pressures were too low for such an orientation to be produced. Axial distribution analyses of quartzites in the Bendigo district (Beavis 1964b) showed that direction groups existed which defined conjugate planes not visible even microscopically. This method has shown the presence of these planes in quartzites wherever examined from this part of the state.

Pressure fringes on hard, relatively large mineral inclusions in slate have been ascribed by Mugge (1933) to rotation of the hard crystals between cleavage planes in the deforming slate. The presence of these fringes can then be regarded as evidence of rotation as one effective mechanism in deformation. Pressure fringes on pyrite in slates have been recorded by Hills (1963) from Bendigo, but they are common in slates throughout the state. In an example from Corop, on the Heathcote axis, the fringes consist of muscovite, calcite and quartz, also showing a preferred dimensional orientation, with kink zones that infrequently are present in the calcite and muscovite. The fringes and the hard porphyroblasts are usually bounded by fine shears.

Mesoscopic Structures

Bedding and Lithological Layering

Beds in the Ordovician rocks range from laminae 1 mm thick to massive sandstones and slates over 10 ft thick. The average thickness of beds, however, is between 1 and 2 ft. Bedding is a prominent feature of the laminated greywackes, but in non-laminated greywackes, quartzites and thick slates, it may be obscure and recognizable only after careful examination for slight colour variations. The nature of the graded bedding, characteristic of the greywackes, has been described

Fig. 3—Primary bedding features in greywackes.
a. Convoluted bedding in fine greywacke, Steiglitz.
b. Pseudo-boudinage in siltstone, Ingliston. Fig. × ½.

by Hills and Thomas (1953) who pointed out that, while graded beds are typical, sharply bounded non-graded beds also occur. Two types of gradation are found: simple and oscillatory. The latter is of particular value in the study of cleavages and small-scale folds.

Fine current bedding is often present in the sandstones, the upper surfaces of which may have fine ripple marks. Primary load casts, intraformational deformation and convoluted bedding point to the high moisture content and plasticity of the sediments at deposition. In places a pseudo-boudinage has been formed during deposition (Fig. 3b).

One of the most significant features of bedding is the lack of persistence of a particular bed. Even quite distinctive beds can rarely be traced for more than a few chains. Bedding as a recognizable structure persists into quite high-grade metamorphic rocks, and it is possible in some instances, at least, to relate lithological layering in high-grade schists and gneisses to original bedding. In the metamorphosed Ordovician rocks of western Victoria no general rule can be formulated relating lithological layering to original bedding, and each case must be individually assessed. For example in the Casterton and Ararat schists, the layering usually clearly represents bedding, with the original gradation preserved and readily recognizable. This gradation may be either simple or oscillatory. However, in both of these areas, some of the layering is of doubtful origin and some is clearly due to metamorphic segregation. Quartz-albite layers are lenticular in a predominantly micaceous matrix, there is no evidence of gradation, and petrographic evidence suggests an original pelitic sediment. In this case, the lithological layering is grossly discordant to that, which can with certainty, be correlated with bedding.

In the Charlton district, the schists in part have a distinct lithological layering which has resulted from transposition of beds, metamorphic segregation having played only a minor role. Here, original bedding lamination has been largely obscured (Fig. 4). Again, however, much of the layering in the schists of this district is due to original bedding.

FIG. 4—Schist showing transposition on *s* planes, Charlton. × $\frac{1}{10}$.

Fracture Cleavage

The distinction between fracture cleavage and strain-slip cleavage is not always clear, and frequently the terms have been interchanged. The term 'fracture cleavage' was introduced by C. K. Leith (1905, 1923) who also equated it with some forms of strain-slip cleavage. Here it is regarded as a series of more or less closely spaced fractures; movements producing the cleavage have not produced any preferred orientation of the minerals in the cleavage or in the rock. The cleavage planes *need not* be either statistically or actually axial plane structures, although they invariably are if the cleavage is due to folding movements. Fracture cleavage has been induced in coarse sandstones adjacent to the Knowsley East Fault, near Heathcote (Fig. 5).

The cleavage is a prominent fabric element with the planes spaced at intervals of ½″ to 3 ft. It has a strong preferred orientation, making an angle of 30° to the fault. It is a shearing phenomenon resulting from stresses set up in the sandstones during the fault movement. The angular relationship between the cleavage planes and the fault defines the sense of slip on the fault. Wilson (1961) showed that the angle between fracture cleavage and the plane of movement reflects the nature of the rocks in which the cleavage occurs. In plastic beds, it is usually an acute angle but in brittle beds it may approach 90°. If this is so it must be inferred that the now brittle sandstones near Heathcote must have been in a plastic condition at the time of fault movement.

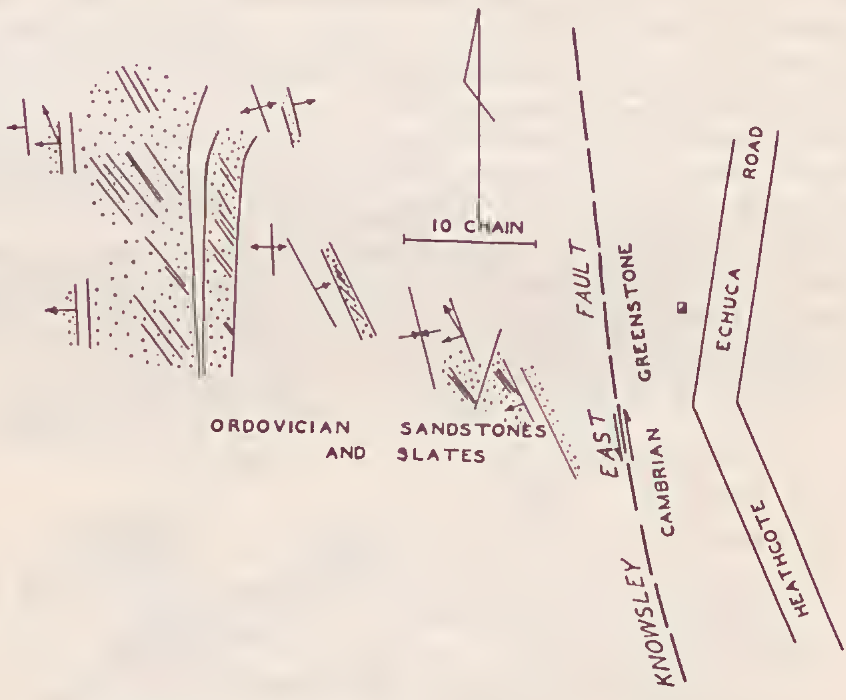

FIG. 5—Map showing fracture cleavage in sandstones, Knowsley East.

Similar fracture cleavage in sandstones has been noted at a few other localities in Western Victoria associated with major faults, e.g. on the Muckleford Fault near Maldon and on the Rowsley Fault near Anakie. Fracture cleavage due to slip on bedding planes during folding does not appear to have formed in the Victorian Ordovician sediments, although it is a prominent structure in the folded Silurian and Devonian sediments in central Victoria. Hills (1963) has described 'fissuring' in sandstones as a fracture cleavage, but this structure has more the features of strain-slip cleavage than of fracture cleavage. The absence of fracture cleavage may be explained by either assuming it was formed in the earlier stages of deformation and was modified in the later stages to a strain-slip cleavage; or, alternatively, it may be that the tectonic environment of the sediments during folding was such that the fracture cleavage was unable to form.

Hills (1963) has recorded true fracture cleavage in an early-formed bedded quartz vein at Castlemaine, due to differential movements on the boundary surfaces. The brittle quartz would tend to fail in this way.

Slaty Cleavage

Slaty cleavage, or flow cleavage, results from the recrystallization of pelitic sediments while they are undergoing internal deformation due to the application of external stresses: it is expressed as a parallel preferred orientation of the fine platy minerals which make up the rocks. Its deformation involves compression normal to the cleavage, and elongation in direction of easiest relief, as well as internal rotation. Elongation was noted by such early workers as Sorby (1843) and Sharpe (1847), and the evidence for this strain phenomenon has been summarized by Fourmarier (1947). In the Ordovician slates of Western Victoria, evidence of elongation is found in deformed graptolites. A detailed study of this deformation was made by Hills and Thomas (1944) who found a compression normal to the cleavage of up to 60 per cent and elongation parallel to the cleavage of up to 25 per cent. The extension of these rocks parallel to the *B* tectonic axis has had a profound effect on the style and symmetry of the mesoscopic folds.

Slaty cleavage is now generally accepted as being the result of laminar flow within the deforming pelites. Maxwell (1962) has suggested, however, that slaty cleavage formation is not necessarily a phase of a metamorphic sequence, and has shown that slaty cleavage may form in the initial stages of folding particularly if a thick sequence of high moisture-content, rapidly subsiding pelites is involved. This idea will be shown to be of considerable importance later in this paper.

Slaty cleavage is an axial plane structure: in the rocks under discussion it is commonly truly parallel to the axial surface of the fold in which it occurs, although sometimes because of curvature due to textural variations, it is only statistically parallel to the axial surface. Fanned slaty cleavage has not been observed on a mesoscopic scale, although this pattern has been recorded macroscopically in the Chewton-Maldon district (Beavis 1964b). In the region west of the Heathcote axis, slaty cleavage, with only local exceptions, dips very steeply to the east, or is vertical. In this region the cleavage is ubiquitous in the Ordovician pelites, but it is absent from the Cambrian rocks and from the Siluro-Devonian rocks of Central Victoria. This has a profound effect on the style of the mesoscopic folds: those of the Ordovician rocks have a near ideal similar style, whereas those of the Cambrian and Siluro-Devonian rocks show some quite pronounced departures from this style.

Where the Ordovician rocks have been recrystallized, there has been an emphasis of the slaty cleavage, which is expressed as a schistosity, but commonly, the dominant foliation in the schists is a layering due to bedding lamination. Axial plane foliation in the schists has usually maintained the simplicity of the original slaty cleavage. In local thermal metamorphism of slates about batholiths, recrystallization has tended to emphasize the slaty cleavage, so that, on a textural basis, the contact rocks 'may be described as schists, rather than hornfelses' (Beavis 1962b).

Slaty cleavage has not been imposed on the sandstones although a fine shear cleavage, geometrically and genetically related to the slaty cleavage, is present in zones of intense deformation. The cleavage is due to flow (shear) in the fine matrix together with a dimensional preferred orientation of the characteristically sliver-like grains of quartz and felspar in the plane of movement. The dimensional orientation of the quartz and felspar results from rotation during cleavage development, or, in some cases, through dislocation of the grains by cleavages. No recrystallization of the quartz is apparent in these cases. This cleavage is most common in the hinge zones of mesoscopic folds where internal stresses would have been quite intense during deformation.

In the western area, the slaty cleavage is typically undeformed; any deformation of this structure is quite local adjacent to major faults (e.g. the Rowsley and Hanover Faults—see Beavis & Beavis, in prep.) and large batholiths such as near Harcourt and Ararat.

Strain-slip Cleavage

In two earlier papers, the writer has discussed strain-slip cleavages in some of the Victorian Ordovician rocks. Strain-slip cleavage consists of laminar domains of intense shearing in which the minerals have undergone considerable reorientation (Knill 1960; Turner & Weiss 1963). It is the reorientation of the minerals, particularly, which distinguishes this form of cleavage from fracture cleavage.

In the coarser greywackes of the Ordovician rocks, strain-slip cleavage tends to be restricted to the hinge zones of mesoscopic folds; where the folding is tight and close, it may occur in the limbs also, in which case the domains are more widely spaced. In beds with uniform texture it is planar, but in graded beds, it is invariably curved. Hills & Thomas (1945) termed the strain-slip cleavage in sandstones 'fissuring' and since this term is generally accepted in Victorian geology, it is well to retain it. Fissuring was described by Hills and Thomas as 'zones varying in width up to about 1 inch, in which the rock is strongly sheared . . . they make a high angle with the bedding . . . and . . . are radially arranged in a fold'.

In the hinge zones of folds, a cuspate structure is associated with the fissuring at the base of the sandstone beds (Plate 23, fig. 2).

The cuspate structure, to be regarded as a rudimentary mullion, is obviously of tectonic origin, and its formation was assisted by the plastic condition of the sediments at the time of folding. It is restricted to hinge zones and the long axis is invariably parallel to the fold axis. The mullions occur in both anticlines and synclines, almost invariably on the lower surface of the bed.

Fine conjugate shears are frequently developed symmetrically about the fissuring. This was noted by Hills and Thomas in the Napoleon Anticline at Bendigo, and has since been observed in a number of other localities (Plate 23, fig. 1). The effect of this conjugate cleavage has been to produce a 'lozenge structure' (Plate 24, fig. 1) on the bedding planes. The long axis of the lozenge structure is parallel to the fold axis.

Small crenulations may be associated with the fissuring in sandstones, particularly in the finer textured sections of oscillatory graded beds (Plate 25, fig. 2). These crenulations lack the complexity of those found in the finer slaty siltstones. A typical example is shown on Fig. 6b.

The fine detail of fissuring can be seen in thin section. Domains not visible mesoscopically may be seen microscopically, indicating that even in quite coarse sandstones, fissuring may be microscopically penetrative. Examples from Bendigo have been figured by Hills (1963) but the most interesting examples recorded during the present survey were at Bristol Hill, Maryborough. Thick, coarse textured sandstones have a fine microscopic cleavage parallel to the mesoscopic fissuring.

A lamprophyre dyke, intrusive into the sandstone and post-dating folding, is also cleaved, the cleavage domains being continuous across the contact, with slight refraction.

The phase of folding, during which fissuring developed, and the nature of the internal stresses developed, are problems at present under investigation. The radial fanned arrangement of the cleavage defines it as *hOl* structure, immediately suggesting tensile fracture: however, the shear characteristics of the cleavage domains tend to preclude this interpretation; moreover, in graded beds, the fissuring passes up into normal strain slip cleavage in the finer textured rocks. The fissuring was formed at a stage when the sandstones and slates were sufficiently plastic for flow zones to develop in them, while the fanned pattern suggests that flexure and bedding plane slip were active mechanisms in the folding process. This, in part, accords with the views of Hills & Thomas that the fissures were essentially 'flow

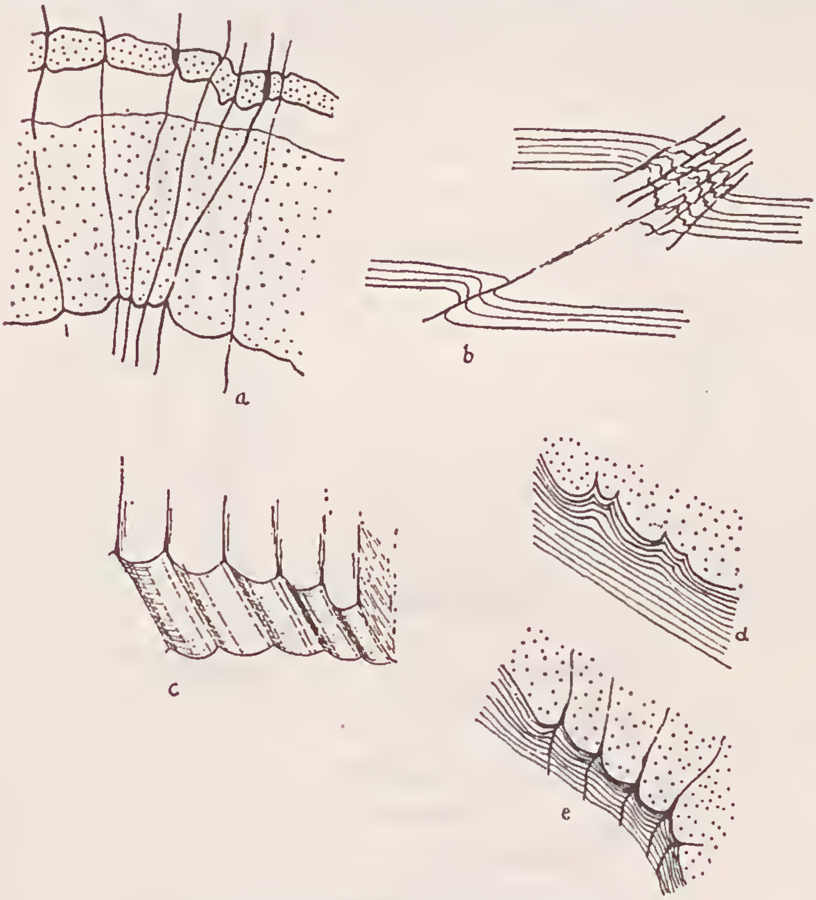

FIG. 6—Strain slip cleavage in sandstones.

a. Fine cleavage domain in metagreywacke, Big Hill, Bendigo. × $\frac{1}{4}$.
b. Fine domain in greywacke, Break O'Day, Kangaroo Flat. × $\frac{1}{8}$.
c. Mullion structure on fissuring, Steiglitz. × $\frac{1}{20}$.
d, e. Fissuring in sandstone, Steiglitz. × $\frac{1}{20}$.

layers in which plastic flow was particularly strong'. The problem is complicated, however, by the mounting body of evidence of two phases of strain-slip cleavage during folding: one synchronously with slaty cleavage while the rocks were plastic, the other at a late stage, when the rocks were brittle.

The sequence of events leading to fissuring can be seen clearly in a series of folds near the junction of Yankee Gully and Grahame's Gully, Steiglitz (Fig. 6d, e). Here in folds with varying degrees of tightness, rudimentary mullions are to be seen in open folds, *without* associated fissuring. In tighter folds, small fissures have formed in the sharp angles of the mullions; the acme of fissuring is to be seen in the tightly appressed folded sandstones. That nicks in the base of the sandstone acted as 'triggers' for fissuring, as suggested by Hills & Thomas, is supported by these observations.

In the finer textured pelitic sediments, the strain-slip cleavage may have one (or more) of the following styles: parallel, continuous first order shears; parallel sets of second order shears; conjugate sets of second order shears. Two generations of strain-slip cleavage have been recognized locally in the region west of the Heath-

FIG. 7—Strain slip cleavage in pelitic sediments.

a. Parallel, continuous first order cleavage, Castlemaine. × ¼.
b. Second order cleavage, Morrisons. × ¼.
c. Conjugate second order cleavage, Sheoaks. × ¼.

cote Axis, while there is evidence of two phases of first-generation strain-slip cleavage. Some examples of the various styles are shown in Fig. 7.

The second order shears normally consist of lenticular domains lying *en echelon.* Each domain has a thickness of from 1 to 5 mm, the thicker being groups of fine shears, individual members of which are visible only microscopically. As pointed out in an earlier paper (Beavis 1964a) both first and second order cleavages show curvature across graded beds, and are refracted at bedding planes.

Small folds associated with the cleavage have a variety of styles. The main factors controlling the style of small folds are lithology and the style of the cleavage. In most cases folding resulted from both movement on the cleavage and flexure of adjacent, often uncleaved laminae.

Extreme movement in which thin beds of plastic sandstone have been involved may result in the disruption of the sandstone laminae to form ovoid fragments (Fig. 7b), the long axes of which lie in the fold axis. This structure is observed only rarely, and then only in intensely deformed zones. The finer sediments curve around the ovoids, the form of which emphasises the importance of rotation and elongation during the imposition of strain-slip cleavage.

In the metamorphic rocks of Western Victoria, strain-slip foliations may have been imposed before, during or after metamorphism. Irrespective of the time relationships of the cleavage and metamorphism the style of the cleavage has been conditioned by rock type.

In considering strain-slip cleavage it is essential to distinguish the relationship of the cleavage to the folding, since there have been shown to be, at least locally, two quite distinct generations of strain-slip cleavage in the Ordovician sediments. The first generation, genetically related to the folding of the rocks, occurs throughout the full distribution of Ordovician rocks west of the Heathcote Axis, but shows an environmental restriction. It is a planar structure statistically parallel to the axial planes of the folds. This strain-slip cleavage is found only in the hinge zones of the mesoscopic folds, and then only in the sandstones and siltstones. It is absent from the pure pelites. Thus, on the Moorabool R. near Meredith, fine textured, tightly folded slates exposed in a quarry lack strain-slip cleavage; downplunge, overlying oscillatory graded siltstones show intense deformation by strain-slip cleavage.

The second-generation strain-slip cleavage recorded in these rocks is very restricted in distribution: to date it has been noted only about the Harcourt Batholith; in the Anakie-Steiglitz area near the Hanover and Rowsley Faults; at Ingliston in the contact aureole of the Ingliston granodiorite, and west of Ararat. This cleavage, with the associated lineations, is the only evidence of multiple deformation of the Ordovician rocks west of the Heathcote Axis, and it is inferred that this group of rocks has, in general, suffered only a single folding.

Although the second-generation strain-slip cleavage has an areal restriction, where it does occur it is *not* controlled by structural environment or lithology as is the first generation. It is found in limbs and hinge zones of folds, and in all of the rock types. It is sharply discordant to the main structures and this geometric discordance reflects a lack of genetic relationship to the main structures.

As well as the two generations of cleavage, it is necessary to consider two phases of strain-slip cleavage in the folding of the rocks. There is some evidence that the strain-slip cleavage of the first generation developed synchronously with the folding of the still plastic sediments. However, in some cases, slates do show *'Gleitbretter'* effects, which could be developed only if the slate were in a brittle condition, i.e. in the later phases of the folding. This effect, noted particularly in the Castlemaine district, may argue a continuous cleavage development, or it may argue this type of strain slip cleavage formation due to renewal of stresses in the late stages of the folding deformation.

LINEAR STRUCTURES

Linear structures are penetrative on the mesoscopic scale; they include lineations *sensu stricto*. The linear structures may be parallel to the direction of movement *a* but, in the rocks under discussion, with one exception, all of the linear structures recorded were parallel to the axes of the folds in which they occurred. Linear structures recorded were: lineations in the bedding (So) due to the intersection of planes of movement (slaty cleavage S_1, strain-slip cleavages S_1^1, S_2); lineations in S_1 and S_1^1 due to the intersection of these by bedding; lineations in S_0, S_1, and S_1^1, due to intersection of these by S_2 (only in the areas of superposed S_2); small crenulations in So (and locally in S_1 due to superposed S_2); lozenge structure; linear preferred orientation of mineral grains in So and S_1; stretched, detached and rotated ovoid fragments; mullions, boudinage and rodding.

In the rocks under discussion, there is, except for the areas mentioned above in which a second generation strain-slip cleavage has been imposed, a single lineation (although several styles may occur in the one exposure). This lineation is, with one exception, parallel to the fold axis, i.e. it is a *B* lineation. The only *a* lineation recorded was in shale S. of Metcalfe. This lineation is a fine striation in So, and may be the result of slip on bedding planes. Lineations in So due to the intersection of this surface by S_1 are very fine microcrenulations, which sometimes have a similarity to very fine ripple marks (Pl. 25, fig. 1). In the coarser pelites this style has a gross form which could be mistaken for a primary structure (Pl. 25, fig. 2) until its intimate relationship to cleavage (S_1^1) and its invariable parallelism to fold axes is established. Lineation in S_1 is a colour banding produced by textural and colour variations in the rock. These bands vary in width up to 1″, and are irregularly spaced.

Very locally, for example near Ballan, fine penetrative conjugate cleavages in pelitic sediments have resulted in a penetrative 'pencil' structure, which is a *B* linear structure. This structure is sometimes reminiscent of flow structure and suggests flow parallel to *B* in a deforming plastic sediment.

Lozenge structure, closely related genetically to the coarse ripple lineation, is due to the intersection of the bedding of coarser greywackes by conjugate strain-slip cleavage (Pl. 24). The boundaries of the lozenges, as well as the long axes, are statistically parallel to *B*. This linear structure is restricted to the base of coarse beds and laminae in the hinge zones of mesoscopic folds.

Small folds, commonly called congruous drag folds, occur frequently in the limbs of mesoscopic folds, but they are not as common as is often believed. They vary in dimensions, and are invariably parallel to the axis of the larger fold in which they occur. Normally, these folds are developed in sandstones, but slates may also be involved. The form and style of the small folds may not accord with that of their hosts. With decreasing size they merge into microcrenulations. Normally ascribed to drag on bedding planes during flexure of the deforming rock mass, some, at least, are due to movement (slip) on cleavage.

Stretched, rolled and detached fragments forming linear structures have been described earlier in this paper (see page 159). The ovoids lie in a line parallel to the fold axis, and their long axes themselves are parallel to this axis. This form of structure implies intense deformation of plastic beds with elongation in, and rotation about, *B*.

The parallel orientation of elongate mineral grains is a characteristic lineation in the crystalline schists of far Western Victoria: amphiboles, micas and ellipsoidal porphyroblasts of cordierite may be involved. Less common is the orientation S_1, of 'spots' of incipient andalusite in hornfelses at igneous contacts. This type is particularly well developed in the Wedderburn-Kingower district.

Throughout the world, mullions seem to have been developed best in high-grade metamophic rocks, although Pilger and Schmidt (1957a, b) recorded them from relatively low-grade rocks in North Eifel. Rudimentary cleavage mullions have been described earlier. Both fold and cleavage mullions have been recorded from Casterton by Wells (1956). Rodding has not been either observed or recorded in the Ordovician rocks W. of the Heathcote Axis.

Boudinage is a rare linear structure: recorded from medium grade schists at Casterton by Wells, this is the only known occurrence in Western Victoria. A rudimentary type has been observed near Meredith and Ballan.

It is noteworthy that rectilineations are rare in the Ordovician rocks. Even on the scale of the handspecimen the lineations are frequently curved. On a larger scale, the curvilineations reflect the reversal of plunge of axes of folds, but on a smaller scale, curvature is due to slight variations in attitude of cleavages resulting from lithological changes.

Throughout the western area of Ordovician rocks, there is a single lineation. Multiple lineations, associated with superposed cleavages, and geometrically and genetically unrelated to the folds, have been noted only about the Harcourt Batholith, in the Ingliston-Anakie-Steiglitz area and the Ararat district. In these cases, there are at least three lineations due to intersections of So and S_1; So and S_2; and S_1 and S_2.

Fold Structures

Folds are the most prominent mesoscopic elements in the structure of the Ordovician rocks. The folds range from minute, barely visible structures, to very large anticlinoria and synclinoria, the existence and form of which can be determined only after detailed stratigraphic and structural mapping. Throughout, the style and geometry of the mesoscopic folds are relatively constant. Local variations are apparently due to lithology: thus the form and geometry of a fold in thin interbedded slates and sandstones will differ from those of a fold in thick slate, thick sandstones, or oscillatory graded greywackes. The style of the mesoscopic fold is everywhere close to 'similar' even where thick, supposedly competent sandstones are involved.

Most of the mesoscopic folds are asymmetric, and slightly overturned. The westerly limb has steeper dip than the easterly; overturning is to the W., with the axial planes dipping steeply E. Superficially the folds have monoclinic symmetry, but consideration of all the elements of a fold shows that the symmetry is usually triclinic. In the geometric terms of Turner & Weiss (1963), the folds can be described as inclined, non-plane, non-cylindrical. The hinge lines are curvilinear and the axial surfaces frequently curved.

One of the most striking features of the mesoscopic folds is the change of plunge, both in the direction and degree within quite short distances: frequently less than 100 ft. An example of this is shown on Pl. 26, fig. 1, from near Woodend. The plate illustrates a cutting on the Calder Highway, almost coincident with the axial surface of a fold. Variation in plunge from a few degrees to over 30° can be seen. Viewed in its broadest sense, this geometry is a typical $B \perp B'$ type, and is characteristic of the folds on all scales. There is a second effect, noted by D. E. Thomas at Chewton, but typical of the Ordovician rocks generally: the transition along the hinge lines of anticlines to synclines and *vice versa* so that an *en echelon* pattern of folds results. This, too, occurs at all scales.

The whole fold system clearly has been influenced by the resistance to elongation in *B*, although some elongation has occurred. This resistance has resulted in buckling on B^1 axes more or less normal to *B*: it would also accentuate flow in *a*. Release of residual stresses in *B* after the cessation of folding would result in the opening of *ac* tension joints: joints which are extremely prominent in these rocks.

As previously noted, the form and style of the mesoscopic folds vary with lithology, but there appears to be little significant variation with stratigraphic position. Any apparent variation with stratigraphic position is a lithological effect—e.g. pre-Darriwilian sediments contain a relatively high proportion of sandstones, while this proportion decreases sharply in the Darriwilian and post-Darriwilian rocks. The folds in slate are sharp with rounded hinges, but they may occasionally be quite angular, or even flat. Flat open folding is more characteristic of the sandstones. Ramsay (1962) discussed the geometry of folds and the mechanism of folding, and showed that, for 'similar' style folds, flattening was important in the deformation. Fig. 8 illustrates the geometry of a typical fold. It will be noted that thinning of the limbs occurs even in the sandstones. This is less severe than in the slates, but it is a persistent feature in the sandstones throughout the sequence.

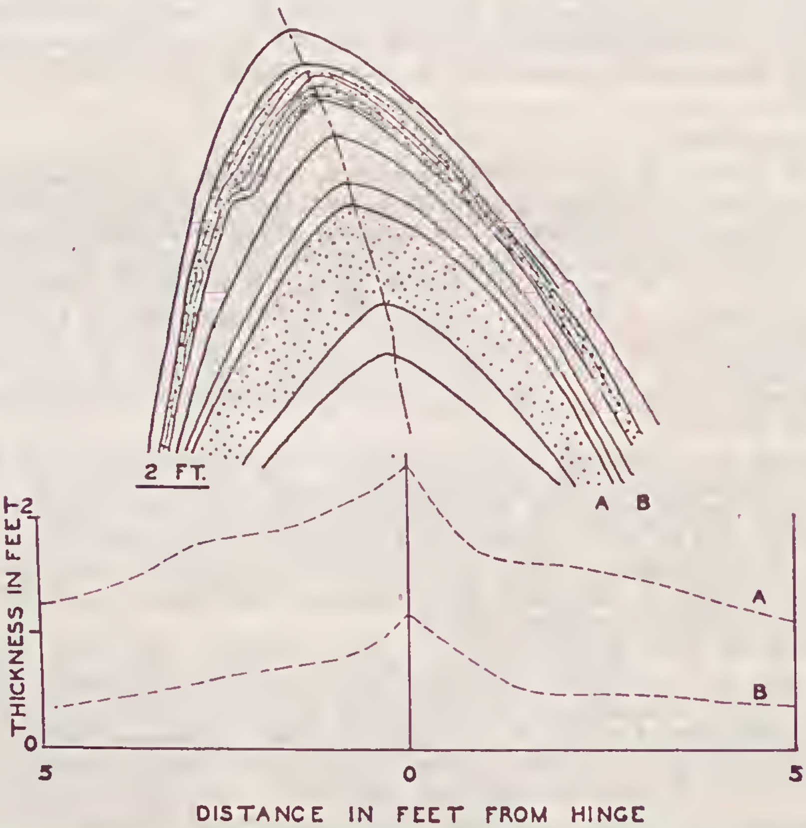

FIG. 8—Geometry of a fold in interbedded slates and sandstones, Castlemaine.

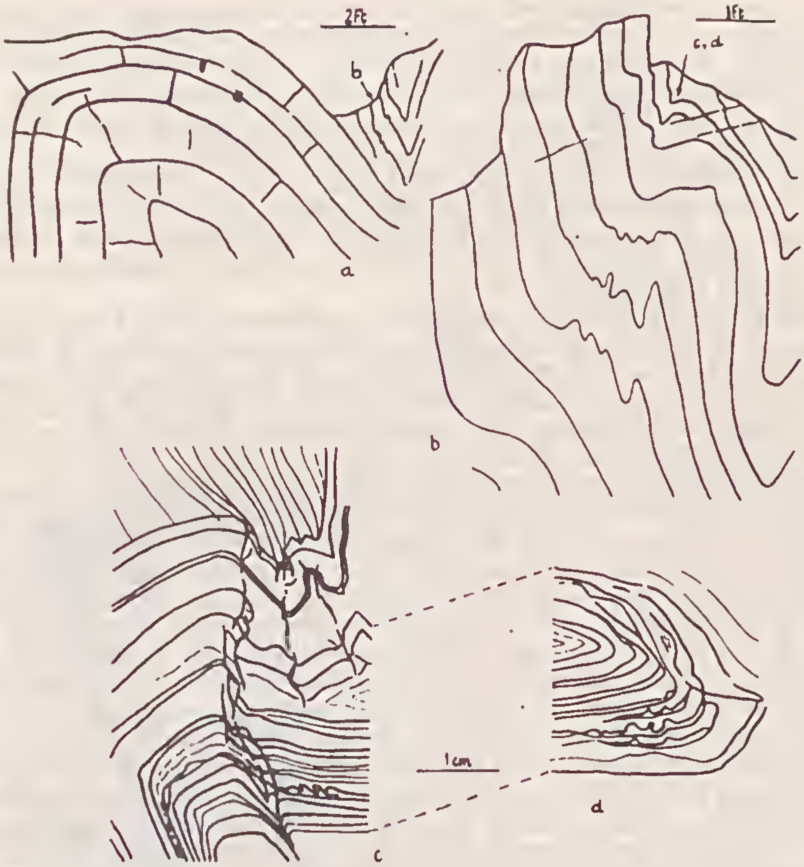

FIG. 9—Anticline in fine textured greywacke, Moorabool R., Meredith.
a. Large scale mesoscopic anticline.
b. Small scale folds on E. limb of (a).
c.-d. Microscopic fold in one limb of (b).

Small-scale folds on the limbs of the larger mesoscopic folds rarely have the same style and geometry as the large folds. This is illustrated for folds at three scales on Fig. 9.

It is likely that the smaller the scale the more important become the internal stresses as factors controlling the form of the fold. Minor textural and lithological variations similarly would assume greater significance. Since small-scale folds tend to be more developed in the hinge zone of mesoscopic folds, it might be enquired whether mesoscopic folds are more frequent, or more complex in the hinge zones of the macroscopic folds. At present there is no evidence to suggest that this is so.

MACROSCOPIC STRUCTURES

FOLDS

Macroscopic folding is known in detail only in the belt of sediments bounded on the west by a N.-S. line through Dunolly and Maryborough, and on the east by the Heathcote Axis, i.e. the belt of graptolite-bearing sediments. Even within this belt, absence of fossiliferous beds and the cover of younger rocks has often resulted in an inability to determine detail. The most westerly of the fossiliferous beds are Lancefieldian; W. from the Muckleford Fault, the highest beds known to occur are Chewtonian, with *Didymograptus protobifidus* along the hinge of the Werona Synclinorium. The Muckleford Fault, then, would appear to mark an important boundary in the fossiliferous rocks of the Western Trough.

In the extreme W., the only structural mapping which has defined macroscopic folds is that of Clappison (1960) at Stawell. Here, an anticlinorium and a synclinorium have been mapped: both structures have tightly folded western links, while the eastern limbs have been sheared out. Plunge is gentle, but dome and basin structure is apparent.

In the Ballarat district, the mapping of Baragwanath (1917) has suggested the development of anticlinoria and synclinoria, but the most westerly of such macrofolds, for which there is indisputable evidence, is the Werona Synclinorium, succeeded to the east by the Maldon Anticlinorium. To the south is the imperfectly known Elaine Anticlinorium; the eastern boundary of these two anticlinoria is formed by the Muckleford Fault.

Easterly from the Muckleford Fault, all of the graptolite zones are represented, from basal Lancefieldian through to Bolindian. The Upper Ordovician zones are restricted to a narrow belt in the Riddell Synclinorium, immediately W. of the Heathcote Axis. Between the Muckleford Fault and the Heathcote Axis, the Riddell Synclinorium is by far the largest macrofold and tends to dominate the structure. In the N. Castlemanian beds are exposed: due to southerly plunge, these are succeeded to the S. by Yapeenian, Darriwilian and Upper Ordovician beds. This occurrence of Upper Ordovician W. of the Heathcote Axis is unique, and it is significant that these beds are restricted to the eastern-most sector.

The axes of the known macrofolds have a trend usually a few degrees W. of N.; all, however, show a slight curvature concave westerly, a feature also of the Heathcote and Dookie-Tatong Axes. Except locally, the axial surfaces of the mesoscopic folds have a steep easterly dip, and the folds are slightly overturned to the W. It is reasonable to assume that the macrofolds, similarly, show this westerly overturning. In the region occupied by the Expedition Pass Synclinorium, the Trentham Anticlinorium and the Muckleford Synclinorium, the axial surfaces are fanned (Beavis 1964b), a feature related to past folding deformation by the Harcourt Batholith.

In order more fully to investigate the geometry of the macrofolds, a part of the Axedale Anticlinorium was studied. The area selected, lying to the SW. of the township of Axedale, had previously been mapped in part by J. J. Caldwell (1931). New collections of graptolites were made from Caldwell's localities, and new fossil localities were discovered and zoned. More structural data (bedding, cleavage, lineations, fold hinges) than shown by Caldwell were also assembled. The data and the interpretation of these data are shown on Fig. 10.

It must be noted that, because of the scarcity of fossils, detailed zoning was not possible in the Lancefieldian and that it was necessary, in some instances, to map as one unit, two or more zones (e.g. Be 1 and Be 2).

Statistically, the fold axes have a plunge 15° NNW. Local reversal of plunge occurs but southerly plunge is rare. Dips of the beds are steep and the axial surfaces of the mesoscopic folds have steep easterly dip. Slates predominate, but the Lancefieldian belt is marked by abundant thick beds of relatively coarse sandstones and there appears to be a macro-gradation through the sequence.

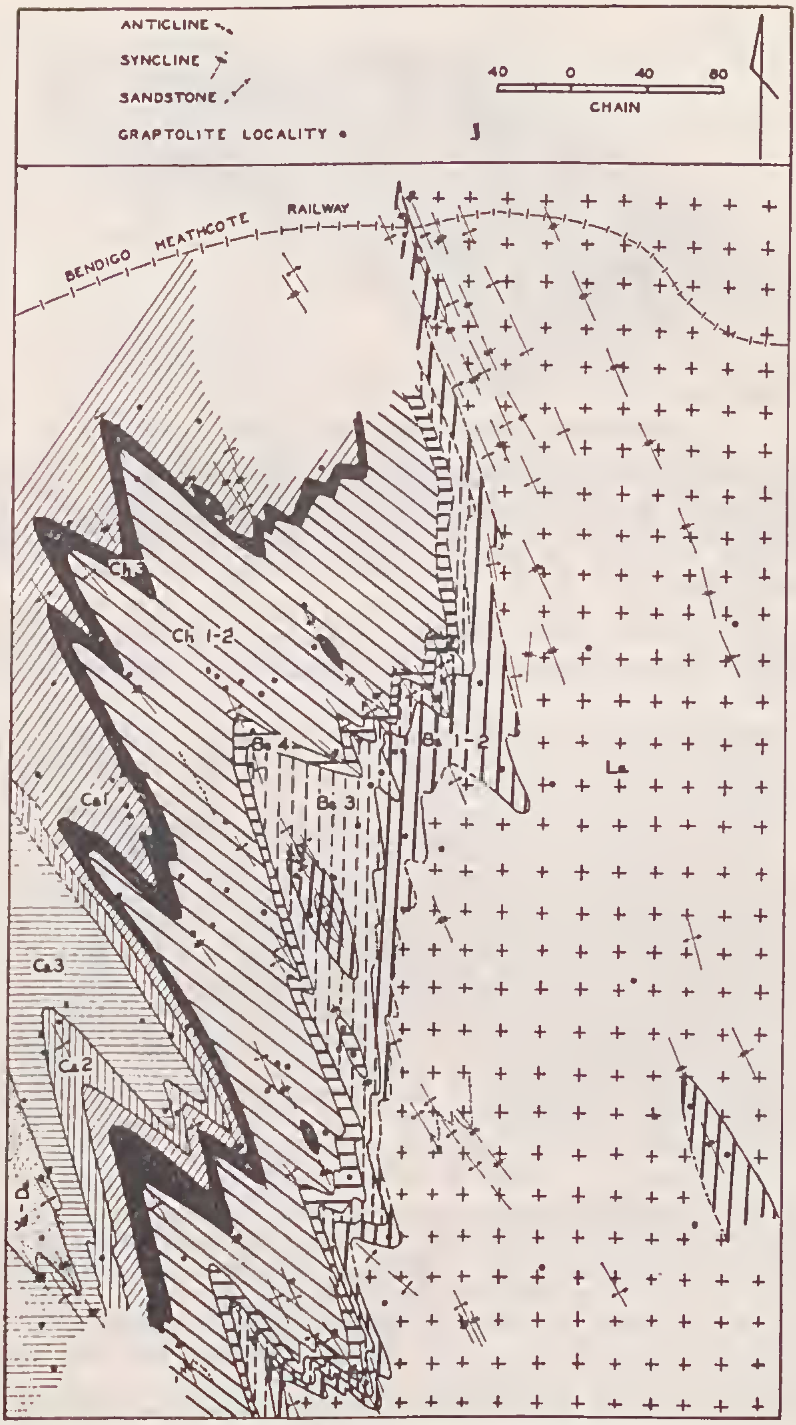

FIG. 10—Map of part of the Axedale Anticlinorium compiled from the writer's data and J. J. Caldwell's published map.

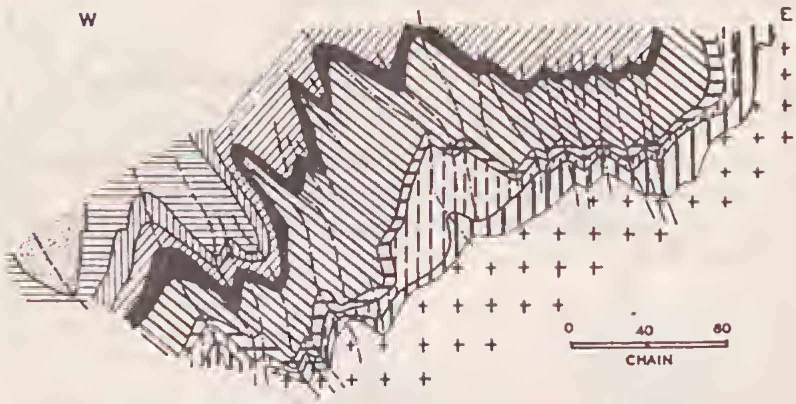

FIG. 11—Tectonic profile of part of the Axedale Anticlinorium.

On the macroscale, the map suggests similar style folding, with marked thickening in the hinge zones, particularly in the hinge zone of the anticlinal in the west-central sector, and thinning of the limbs. To illustrate the macrofold geometry, a tectonic profile (Fig. 11) was prepared. The profile is based on the assumption of a constant plunge of 15° WNW.

The tectonic profile, normal to the axis of the macrofold, demonstrates the precise geometry of the fold. The comparative simplicity of the folding in the Lancefieldian and lower Bendigonian beds, predominantly sandstones, can be con-

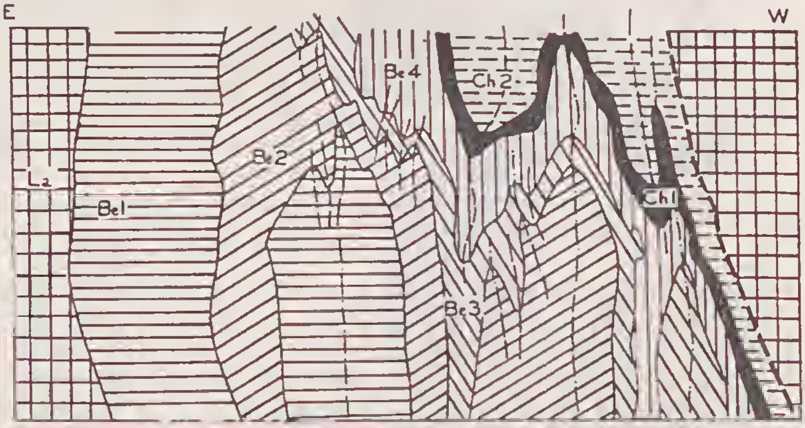

FIG. 12—Tectonic profile of part of the Werona Synclinorium, based on map by Harris and Thomas, 1948.

trasted with the more tortuous structure higher in the sequence. There is also a suggestion of increasing complexity low in the sequence as the centre of the syncline in the west is approached. Perhaps the most important feature of the profile, however, is the evidence of movement towards the W., with curved and inclined axial surfaces. It is clear too that the style of the macroscopic folding, in the structure at least, shows some significant departures from the almost ideal similar style of the mesoscopic folds.

A profile was also prepared for part of the Werona Synclinorium (Fig. 12) from the published map of Harris & Thomas (1948), where the regional plunge is southerly. Again, field checks were made and additional structural data collected.

This profile shows a number of features comparable with those noted for the Axedale structure. There is increasing tightness of folding higher in the sequence and towards the hinge zone of the macrofold; impersistence of individual folds as departures from the ideal similar style are also to be noted. There is a suggestion in this profile of irregular zonal boundaries low in the sequence, which *may* imply contemporaneous erosion. In some other areas there is evidence of poor development of some zones and it might be questioned whether there might not be locally throughout the sequence, small disconformities.

Study of the profiles and of published detailed maps shows that while folding tends to increase in complexity in the hinge zone of the synclinoria, it appears to be relatively simple in the hinge zones of anticlinoria. This is most certainly due to lithology. The Lancefieldian-Bendigonian beds have a very high proportion of sandstones. Higher in the sequence, the proportion of sandstones decreases, and slates and shales become more important.

The other possibility must not be excluded, viz. that, because of the scarcity of fossils in the Lancefieldian, zonal mapping without the detail possible higher in the sequence results in *appearance* only, of simplicity and in fact the folding might be uniformly complex throughout. With the evidence at present available, however, the former hypothesis is the more attractive.

FAULTS

Major faults are known with certainty only in the belt of fossiliferous rocks, or where younger, renewed movement has left a pronounced escarpment. As noted by Harris & Thomas (1948), the stratigraphic relationship on the faults is one in which the lower parts of the sequence (Lancefieldian and Bendigonian) occur on the W. of the fault, and abut against rocks high in the sequence, which occur on the E. side. Many of the more important faults have a meridional, or near meridional trend, e.g. Muckleford, Campbelltown, Rowsley, Djerriwarrh and Whitelaw Faults, but a few, such as the Hanover Fault, cut obliquely across the strike of the sediments.

All have been regarded as high-angle thrusts, movement on which post-dated the folding of the Ordovician rocks. On many of the faults, e.g. Whitelaw and Muckleford, renewal of movement took place in the Tertiary. Late movement on these faults is often reflected in well developed escarpments, although some of the escarpments may be rather the result of differential erosion, e.g. the massive sandstones on the W. side of the Whitelaw Fault abut against soft shales on the E.

The relationships along the Muckleford Fault mark this structure as one of special significance. With the exception of a small occurrence of Chewtonian on the hinge of the Werona Synclinorium, only Lancefieldian and Bendigonian beds occur W. of the fault. This raises the question of whether any significant post-Bendigonian deposition took place W. of the fault. It is suggested here that the Muckleford Fault was an active structure during deposition and folding of the sediments, and that the Western Trough, W. of the Muckleford Fault, ceased to exist in the Chewtonian. Thereafter, deposition was restricted to a narrow trough confined between the Muckleford Fault and the Heathcote Axis. This implies also that the Muckleford Fault was a normal fault downthrow to the E. rather than a thrust, with upthrow to the E.

First recognized in East Talbot (Harris & Thomas 1933) the Muckleford Fault has been traced from W. of Bendigo where the Ordovician rocks disappear beneath the alluvium of the Northern Plains, S. to Maude, where the Ordovician rocks are covered by Tertiary marine sediments. (In this latter area, it was named the Meredith Fault by Harris & Thomas 1949. They suggested that the Meredith Fault might be a southerly continuation of the Muckleford Fault—a suggestion verified by work at present in progress in the Steiglitz-Meredith area.)

Detailed work near Guildford (Thomas 1934) showed that the total movement on the Muckleford Fault was of the order of 4,000 ft, with displacement of Tertiary gravels by 100 ft, and of Newer Basalt by 50 ft. It has been shown by the present writer (Beavis 1964b) that the Muckleford Fault transects the Harcourt Batholith with crushing of the granodiorite.

We may picture as the tectonic effect of the Muckleford Fault, deposition of Castlemanian through to Upper Ordovician confined to a long narrow deforming trough bounded by the Muckleford Fault and the Heathcote Axis, the Muckleford Fault being regarded as a fault unconformity. Deformation within this trough was such that, by the end of the Darriwilian, the major folds were fully developed and the Upper Ordovician sedimentation was confined to a shallow basin in the Riddell Synclinorium.

The western boundary of the Upper Ordovician sediments S. of Gisborne may be faulted, the boundary structure being the Djerriwarrh Fault (Harris & Crawford 1921). Re-examination of the area, using Harris's field map, has shown that, on the W. side of the fault, Chewtonian, Castlemanian, Yapeenian and Darriwilian graptolites occur, while to the E., Gisbornian graptolites are abundant. The displacement on the fault is therefore not great, and again it is possible that the structure is a fault-unconformity.

The displacement on the Hanover Fault, first mapped by W. H. Ferguson (1940), also appears to be small and it is possible that the strike-slip component of movement was important (Beavis & Beavis, in prep.). Chewtonian beds north of the fault, abut against Darriwilian, but work in progress shows over a considerable length Yapeenian and Darriwilian abutting against Darriwilian.

The remaining major fault known is the Whitelaw Fault, first recorded by W. J. Harris (1933). Here Lancefieldian and Bendigonian sandstones and thin slates abut against Darriwilian shales and slates. While displacement is considerable and exceeds that on the Muckleford Fault (5,000 ft) the tectonic significance of this structure does not appear to match that of the Muckleford Fault.

Ordovician Rocks East of the Dookie-Tatong Axis

With the exception of small very restricted areas in the Mornington Peninsula and small faulted inliers in Gippsland, all Ordovician rocks in eastern Victoria occur to the E. of the Dookie-Tatong Axis. With few exceptions, these rocks are unfossiliferous, but where fossils occur, they are Upper Darriwilian, or, more frequently, Upper Ordovician forms. It is generally accepted on this evidence that the Ordovician rocks of the Eastern Trough are of Upper Ordovician age. In contrast to the rocks of the Western Trough, even the so called 'sediments' show a somewhat higher grade of regional metamorphism, while the centre of the area is occupied by a belt of schists and gneisses known as the Metamorphic Complex of north-east Victoria.

Published studies of the structure of the Eastern Trough have been infrequent, and hence little is known of the structure generally, which in any case is much more complex than that of the Lower Ordovician rocks in Western Victoria. Virtually all the geological studies have been concentrated in and about the Metamorphic Complex.

Microscopic Structures

Petrofabric analyses of the rocks have been restricted to a few schists and gneisses of the Bogong High Plains area (Beavis 1962a) and of the Beechworth area (Beavis 1963; Leggo 1965). The quartz and mica subfabrics have, in general, a monoclinic fabric, although the quartz subfabrics of the coarser greywackes may be triclinic.

Almost invariably the biotite subfabric of the crystalline schists is represented by a single maximum defining the single foliation, although in some of the low-grade schists, the maximum to the (001) biotite shows considerable spread due to two acutely intersection foliations; [0001] quartz generally lies in a girdle coincident with the foliation. In the crystalline high-grade schists there is usually a single girdle, but in the low-grade schists as many as three girdles have been found, corresponding to three foliations in the schist.

For various reasons discussed later in the paper, microscopic examination of the rocks in this region is often essential to ascertain the precise nature of a structural element under observation. Such examination may reveal other structural elements. Spindle structure (Beavis 1964c) is a typical example. This structure was first recorded in multi-deformed hornfels from Beechworth, but has subsequently been found elsewhere in NE. Victoria, e.g. at Mitta Mitta. These small quartz spindles parallel the axes of folds in which they occur, and for this reason they are of considerable value in geometric analysis. Like the more gross rodding described by Wilson (1953) they owe their origin to segregation of quartz from the fine laminae in which they occur.

Mesoscopic Structures

Bedding and Lithological Layering

Bedding is difficult to detect in thick slates and pelitic schists, but the greywackes and their metamorphic equivalents have a clear internal bedding lamination. Graded bedding is characteristic of the coarser textured rocks, and may be simple or oscillatory. In some cases, segregation of quartz has occurred in the hinges of small folds, which imparts, in the field, the appearance of a second lamination. Fine current bedding and fine ripple marks have been recorded in the sediments, but have not yet been recognized in the crystalline rocks.

In an earlier work (Beavis 1962a) it was stated that for the Bogong High Plains area, 'in the slate, bedding is the only *s* surface uniformly developed' and that cleavage in the slates is usually, but not invariably parallel to the bedding. It was also stated that the foliation of the schists in this region was parallel to the bedding in the parent sediments. More recent study has shown that the first of these statements is erroneous: in fact, slaty cleavage S_1, is usually the dominant planar surface in the slates, and constitutes the form surface of many mesoscopic folds. However, examination in thin section under the microscope may be essential to determine the nature of the mesoscopic *s*. This is illustrated by Pl. 27, fig. 2. The second statement, that cleavage and bedding are parallel, is also erroneous, at least in part. Throughout the Eastern belt of Ordovician rocks, the slaty cleavage cuts acutely across, or is parallel to, the bedding, on the limbs of folds. In the hinge zones of folds, the cleavage may intersect the bedding at right angles. Since, as will be shown, superposed folding has occurred on a regional scale in eastern Victoria, the bedding-cleavage relationships depend on the nature and generation of the cleavage and also on the nature of the form surface of the folds.

The nature of the foliation in the schists is uncertain. Since the earlier work cited, further evidence has been obtained to show that in some of the low-grade schists at least, the lamination is not primary but is a result of metamorphic segregation into lenticular quartz-albite laminae alternating with continuous quartz-chlorite-biotite laminae, often transected by strain-slip (crenulation) cleavage. It is quite clear, however, that the high-grade schists and gneisses possess a single foliation, in contrast to the two imposed foliations in the lower-grade rocks on the margins of the Metamorphic Complex.

CLEAVAGES AND FOLDING

In the more westerly exposure of the Ordovician rocks, as for example in the Mt. Wellington area, there is a slaty cleavage and, in the hinge zones of folds, in the more arenaceous sediments, an axial plane strain-slip cleavage more or less synchronous with the slaty cleavage. There is, however, a second-generation strain-slip cleavage (crenulation cleavage) sporadically developed. As one goes further E., the crenulation cleavage becomes more pronounced and often becomes almost a penetrative foliation. In the Ordovician rocks of eastern Victoria there is evidence of three generations of folding, of which two have taken place on a regional scale, and one only locally.

(i) *First Generation Mesoscopic Structures:*

Folds of the first (F_1) generation include macroscopic structures, the form and geometry of which can only be surmised, as well as mesoscopic folds with hinges at intervals of from 10 to 250 ft (Fig. 13). The mesoscopic F_1 folds may be open

FIG. 13—First generation folds.

a. Road section near Sambas Mine, Harrietville. Length of section 55 ft.
b. Road Section on the Omeo Highway, 1½ miles S. of Mitta Mitta. Length of section 32 ft.
c. Road section on Omeo Highway, 5 miles S. of Mitta Mitta. Length of section 8 ft.

(Fig. 13a) or they may be tightly appressed (Pl. 27, fig. 1). They are asymmetric, slightly overturned with usually a westerly vergence, although there are well defined belts in which the vergence is easterly. The axial surfaces are curved (Fig. 13b) and the hinge lines curvilinear. The non-plane non-cylindrical geometry of the F_1 mesoscopic folds is due almost entirely to superposed folding.

The folds have aspects of both the similar and parallel styles, with the former predominating, particularly in thick pelitic sequences. The gross configuration of the folds is highly variable. Both flexural slip and flow operated as mechanisms of the F_1 folding, but flow seems to have been the more important.

In the hinge zones of the mesoscopic F_1 folds, smaller folds, with maximum size of 6″, have been formed due to intense internal stresses in these zones. These $F_1{}^1$ folds are associated with movement on strain-slip cleavage, $S_1{}^1$. They occur in the coarser pelites and the finer arenites, but have not been observed in slates, phyllites, or the coarser sandstones. A wide variety of styles has been noted: hinges are frequently sharp, but never angular (Fig. 14), while the limbs are frequently dislocated by $S_1{}^1$. The geometry of the $F_1{}^1$ folds accords precisely with that of the larger F_1 folds in which they occur, and the two groups of structures are clearly of the same generation.

Small conjugate folds are relatively common $F_1{}^1$ styles. These are of two types: one is due to fanned strain-slip cleavage (Fig. 14b), the other to conjugate strain-

FIG. 14—$F_1{}^1$ Fold Styles.
a. Similar style fold from F_1 anticline, Bon Accord Spur, Hotham. × ½.
b. Conjugate fold from F_1 syncline, Harrietville. × 1.
c. Conjugate fold from F_1 anticline, Mt. St. Bernard. × ½.

slip cleavage (Fig. 14c). Small *microcoulisse* and geniculate folds have been noted, but similar style small folds are by far the commonest. The axial surfaces of the $F_1{}^1$ folds are curved and are parallel to $S_1{}^1$. The cleavage domains themselves may be arrays of second-order shear but they are usually continuous first-order shears, 0·5 mm thick, and spaced at intervals of from 1·5 to 3·0 mm. In places, the prolongation of the deforming stresses has resulted in $S_1{}^1$ becoming a microscopically penetrative foliation.

Lineation, L_1, parallel to the axes of F_1 folds tends to be restricted to the pelitic rocks. Two styles are common; lithological banding in S_1, and micro-

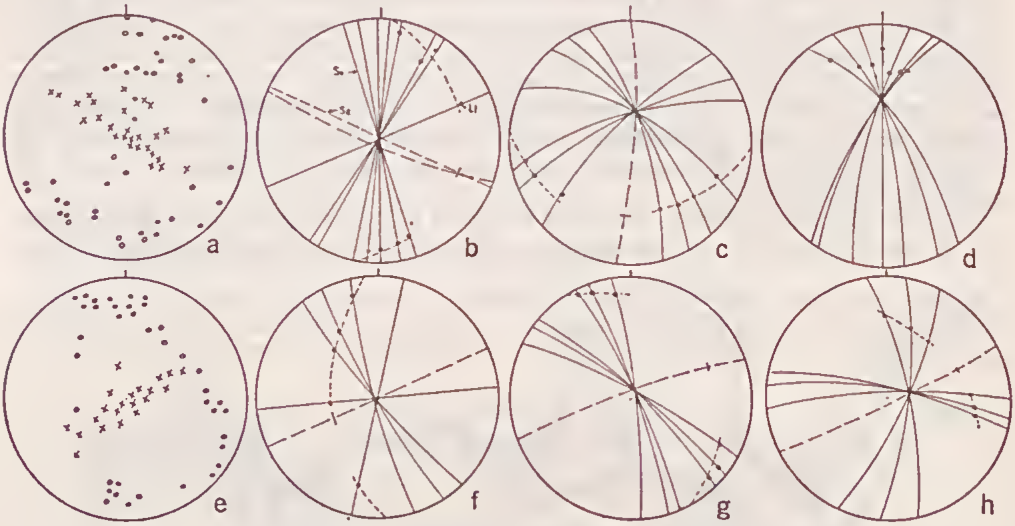

FIG. 15—Geometry of F_1 and F_2 Folds.
a. Lineations in the Mitta Mitta Area. L_1 o; L_2 x.
b. Geometry of F_2 Fold, Magorra Gap, Mitta Mitta.
c. Geometry of F_2 Fold, Snowy Ck. West.
d. Geometry of F_2 Fold, Granite Flat.
e. Lineations in the Upper Ovens Area. L_1 o; L_2 x.
f. Geometry of F_2 Fold, Harrietville.
g. Geometry of F_2 Fold, Mt. St. Bernard.
h. Geometry of F_2 Fold, Mt. Feathertop.

crenulations of S_0. This latter style is found also as a second generation lineation, so that it is not a unique F_1 structure. Where it is an F_2 structure, however, it lies in both S_0 and S_1, so that distinction is usually possible. Lithological banding, a deformed example of which is shown on Pl. 30, has a width ranging from 1 mm to 1 cm. The microcrenulations have a wavelength of 1 mm or less. Lineation $L_1{}^1$, parallel to the axes of both F_1 and $F_1{}^1$ folds, consists of broadly spaced crenulations in S_0 due to the intersection of this surface by $S_1{}^1$. Mullions, typically F_2 structures, were recorded as $L_1{}^1$ at only one locality, on the Alpine Highway, 1 mile S. of Harrietville. L_1 and $L_1{}^1$, and hence the axes of F_1 and $F_1{}^1$ folds generally plunge gently, plunges in excess of 30° being rare. This is shown on Fig. 15 for the Mitta Mitta and Ovens Valley areas. Fig. 15 also illustrates the geometry of F_2 folds.

(ii) *Second-generation Mesoscopic Structures:*

The second-generation foliation, S_2, is a strain-slip (crenulation) cleavage, totally penetrative on the mesoscopic scale, but microscopically, tending to be restricted to definite discrete domains. It is statistically parallel to the axial surfaces of F_2 folds. The mesoscopic F_2 folds are small, with an average distance between hinges of about 1 ft, but hinge spacing of up to 3 ft has been noted. It is not unlikely, as will be discussed later, that F_2 folds have been developed on a macroscopic scale. Mesoscopic F_2 folds are found in all rock types, and lithology seems to have exerted a quite considerable control on the style of the fold. In medium

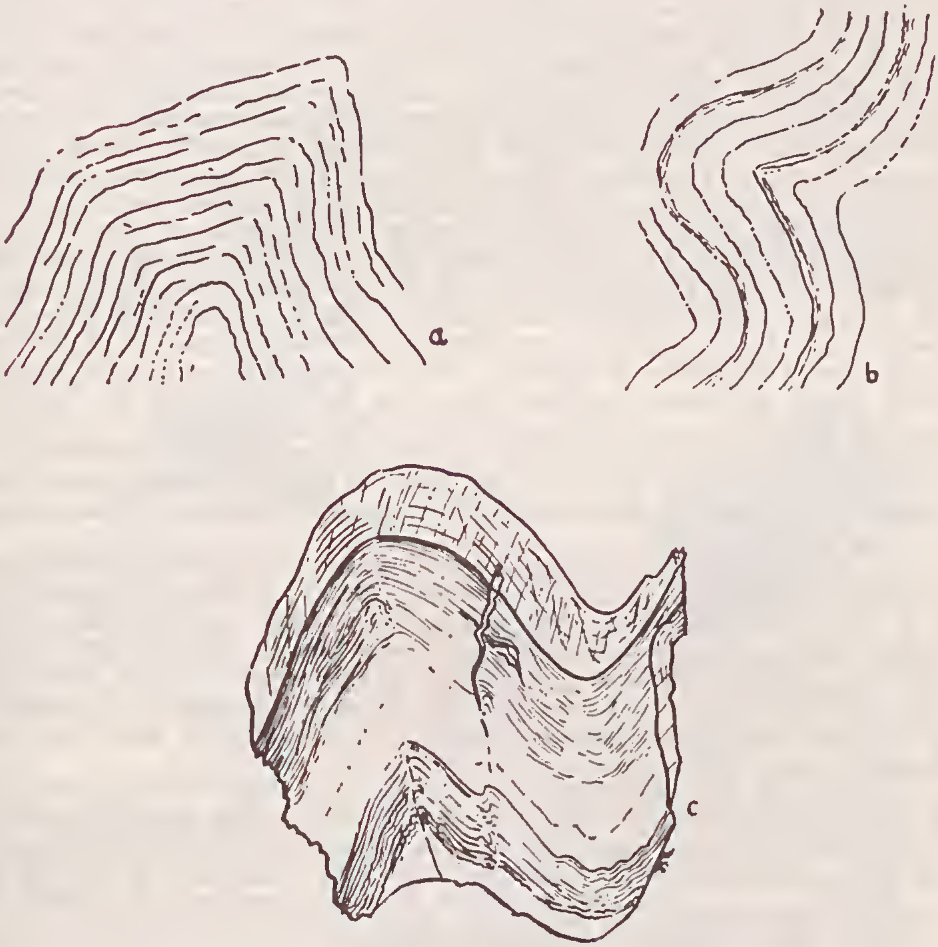

FIG. 16—F_2 Fold Styles.

a. F_2 Fold in phyllitic greywacke, with S_0 as the form surface, Mt. Blowhard. (Blowhard Style.)
b. F_2 Fold, parallel style, in hornfelsic greywacke, Snowy Ck. West.
c. Magorra Style F_2 Fold, Magorra Gap, Mitta Mitta.
All drawings × $\frac{1}{10}$.

textured greywackes, the folds have an almost ideal parallel style (Fig. 16a, b) with hinges varying from rounded and open, to cuspate. Cleavage is absent from these folds, the form surface of which is S_0. The folding mechanism was obviously flexural slip. In many examples of folds of this style, recognition as F_2 structures was not certain unless they contained deformed L_1, and/or their geometry was strongly discordant to the F_1 geometry. Pl. 29, fig. 2 is an example of one of these folds which does contain a faint deformed L_1.

Because F_2 folds of the same style are found typically in certain areas, local names have, for convenience, been given to these styles which reflect primarily lithology and degree of deformation. The *Blowhard Style* is a parallel fold developed in greywacke as a result of flexural slip. The form surface is S_0, and imposed foliations are usually absent (Fig. 16a, b, and Pl. 29, fig. 2). The *Feathertop Style* is found in the finest phyllites (Pl. 27, fig. 2); the hinges are well rounded, and the form surface is the slaty cleavage S_1. There is a closely spaced axial plane strain-slip cleavage, S_2, on which folding occurred by slip. This cleavage becomes a totally penetrative foliation in cases of extreme deformation and the fold becomes indistinguishable from F_1 styles. The *Tawonga Style* folds (Pl. 28, fig. 2) are comparable to the Feathertop style, but are restricted to chlorite-quartz-albite schists. There is a widely spaced axial plane strain-slip cleavage; the form surface is a lithological layering tentatively identified as S_1. *Magorra Style* folds have been described by Hills (1963) as fold mullions. The form surface of the rounded folds may be S_0 or S_1, and folding was by slip on the axial plane strain-slip cleavage S_2. This style of fold is normally found in fine, oscillatory graded siltstones. *Snowy Creek Style* folds (Pl. 28, fig. 1) have sharp but rounded hinges, with S_2 restricted to the actual axial planes of the folds. The form surface is S_1, and the folds are found only in the coarser phyllites. *Harrietville Style* folding (Pl. 29, fig. 1) is found in very fine textured greywacke type rocks and phyllites. The folds are gentle flexures of S_0 or S_1. Often, as in the figured example, the intersection of the two generations of linear structures has produced a lozenge pattern on the form surface. Deformation appears to have resulted from slip on S_2, and flexural slip of the form surface.

Second generation lineations and linear structures, L_2, are of four main styles: fine microcrenulations in S_0 and S_1 of phyllites, angular crenulations, spaced at ¼″ to ½″ intervals in the less fine textured rocks, cleavage and fold mullions, and rodding. The best example of rodding was observed at the Sambas Mine, Harrietville. The quartz rods have been imperfectly formed parallel to the F_2 fold hinges. They were found only in slates and phyllites, and owe their origin to segregation of quartz from these rocks. Similar structures, on a microscopic scale, have been recorded from near Beechworth (Beavis 1964c).

F_2 folds and their lineations plunge steeply, in marked contrast to the plunge of the F_1 structures which is almost invariably gentle. Plunge ranges from 40° to vertical, with 75° to 90° most common. The axial surfaces are usually planar, and the hinge lines rectilinear, at least on the mesoscopic scale. There is evidence from the Mitta Mitta region that macroscopic F_2 folds have curvilinear hinge lines.

(iii) *Third Generation Mesoscopic Structures:*

It is known that a third generation of folding has occurred locally in the Beechworth District, associated with plutonic intrusive activity (Beavis 1964c). During the present work, further evidence of an F_3 folding has been obtained, but it is apparent that, while the F_2 deformation was regional, the F_3 occurred only locally near batholiths and major faults. Four separate styles of F_3 folds have been recorded, and, as with the F_2 folds, style has been controlled largely by lithology.

Mitta Mitta Style folds (Fig. 17b) occur only in fine slates, phyllites, and microlaminated chlorite-quartz-albite schists, and to date have been noted at only two localities: near the junction of Snowy Ck. West with the main stream, and near the head of Swift's Ck. In both cases they are associated with major faults. The folds are chevron style, identical with the Shotover folds described by Wood (1963) from the Otago Schists. The folds have sharp, angular hinges, with steep axial surfaces. The axial surfaces are open fracture cleavage planes, S_3. Axial plane separation is unequal, ranging from a few inches to 3 ft.

The *Murmungee Style* folds are also chevron folds, but these are restricted to hornfelsic greywackes and schists in the contact zones of granitic batholiths. The profiles are sharply angular, and there is a well defined axial plane strain-slip cleavage. This cleavage, which is usually developed in one set of limbs only, appears on earlier foliation surfaces as bands of linear structures (Pl. 28, fig. 3). Intersection of S_3 by earlier formed S defines a lineation L_3. A rare F_3 fold is the *Wandiligong Style* (Fig. 17a), which was observed only in the Upper Ovens Valley. Bend-glide and shear have been the folding mechanisms, and there is no obvious systematic development of S_3. Any cleavage is a shear structure restricted to the hinge zone of the fold. There is no true axial plane S_3.

The *Hotham Style* folds lack the angularity of the other F_3 styles. They are extremely small, and might be more properly regarded as linear structures (Pl. 30). They are found only in phyllites and phyllitic slates. The hinges are rounded, and the size of individual folds rarely exceeds ½″. Pl. 30 shows also the multiplicity of lineations in the rocks which have suffered all three deformations.

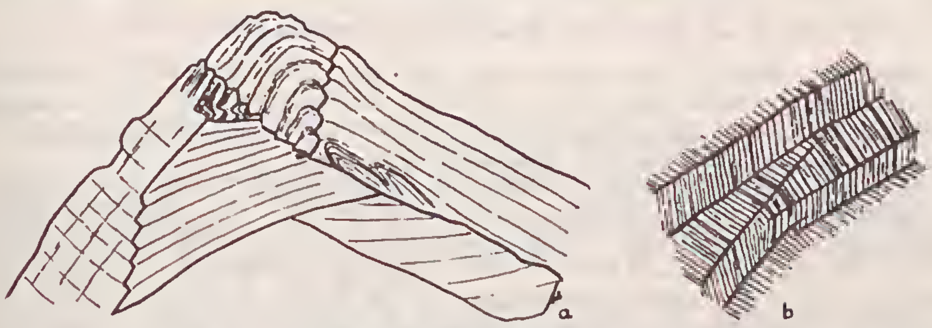

FIG. 17—F_3 Fold Styles.
a. Wandiligong Style Fold, Wandiligong.
b. Mitta Mitta Style Folds in phyllites, Snowy Ck.
Drawings × ½.

Three foliations and associated lineations have also been recorded from the Orbost area (Beavis 1965). In chlorite-quartz-albite schists, transposition of bedding and earlier foliations is clearly seen, producing F_3 folds as small, hook-like structures.

Hoeppener (1956) and others have shown that it is possible for F_2 folds to pass into F_1 folds as a result of continued deformation: S_2 becomes microscopically totally penetrative. The only example of this noted during the present study was in a small area near Tawonga South. Generally non-parallel L_1 and L_2 are ubiquitous in the pelites, with L_1 invariably deformed. Where no imposed foliation, or only a single foliation, is associated with this lineation pattern, the two lineations of themselves are insufficient evidence of two deformations. Where F_2 style folds occur,

L_1 is invariably deformed, and curved around the hinges of the F_2 structures. Where F_1 and F_2 folds occur together, the hinge lines and axial surfaces are non-parallel, and S_1 is often the form surface of F_2, and is clearly older than F_2 (Fig. 18).

FIG. 18—F_1 and F_2 Folds, Rene's Lookout, Hotham Heights. × ½.

Similarly, where F_3 structures occur, they overprint F_1 and F_2 structures, deforming further these earlier folds, foliations, and lineations. There is a marked difference in style of the structures as can be seen from the descriptions above, and the geometric discordance is invariably strong.

In addition to the mesoscopic evidence of multiple deformation, there is microscopic structural and petrological evidence. Non-parallel quartz and mica girdles (Beavis 1964c, 1965; Leggo 1965) must be regarded as valid evidence. Tattam (1929), Crohn (1949), and Beavis (1962a) have all commented on certain retrograde aspects of the mineral assemblages in the schists. It is not unlikely that retrograde activity was due to post progressive metamorphic stressing. It is possible that the first folding and the syntectonic metamorphism are of Benambran age, but the timing of the second and third deformations is unknown. In particular, the third episode may have taken place at different times in different places, so closely related are the F_3 structures to batholiths and faults which have a wide range of ages. F_2 structures are certainly post-metamorphic.

MACROSCOPIC STRUCTURES

FOLDS

The Ordovician rocks of western Victoria are folded into brachy-anticlinoria and brachy-synclinoria. In central Victoria, detailed mapping has shown that Siluro-Devonian sediments have been deformed into long, continuing structures. In Eastern Victoria, the definition of the macrofolds has not yet been possible, so that the type of macrofolding is unknown. Palaeontological and stratigraphic mapping is not possible in the Ordovician rocks of Eastern Victoria, although lithological mapping currently in progress in the Ensay area by G. W. Williams may be successful in defining macrofolds. Such mapping in the Harrietville region suggests a comparable macrofolding to that of Western Victoria, but the results are not really convincing. The only macrofold in the Ordovician rocks of Eastern Victoria for which there is any real evidence is the Kiewa Anticline (Beavis 1962a). This structure, determined in schists and gneisses by the analysis of structural elements appears to be a long open fold, plunging gently N. with the W. limb sheared out on the West Kiewa Thrust, and the core occupied by biotite-sillimanite gneiss. The fold is overturned to the W.

In the 'sediments' of Eastern Victoria, the only evidence for macrofolds is the persistence of dip in one direction over wide sections, without reversal of grading in beds.

Leggo (1965) has suggested folding into anticlinoria and synclinoria in the Beechworth-Myrtleford area, using this type of evidence. Leggo admits, however, that his interpretation is highly conjectural.

The idea of determining macrostructure using the 'vergence belt' concept which Wood (1963) applied successfully to the Otago Schists, has been considered, but at present the data are inadequate. The attitudes of bedding and S_1 and the purely localized inversion of gradation preclude any possibility of large recumbent folds. It is highly significant, however, that there appear to be well defined belts in which vergence of the mesoscopic F_1 folds is consistent; e.g. in the Kiewa, Omeo, Mitta Mitta and Tambo regions, vergence is westerly, while in the Yackandandah, Tallangatta and Nariel regions it tends to be easterly.

The possibility of macroscopic F_2 folds cannot be excluded. The Magorra Gap, near Mitta Mitta, is on a large structure, described by Kenny (1937) which undoubtedly is F_2, and which approaches the dimensions of the macrofolds of Western Victoria.

Faults

Although determination of faults on stratigraphic evidence is rarely possible in this region, detailed lithological and structural mapping has been successful in locating a number of major faults, particularly in, and about, the metamorphic complex. Virtually all of the faults so far recorded are marked by wide belts of cataclastic rock, both breccias and mylonites. High-angle thrusts, low-angle thrusts, and wrench faults have been recorded.

The Nelse Fault, a sinistral wrench, has displaced the schist gneiss transition on the Bogong High Plains some 14 miles. This fault is marked by a zone of mylonite about 50 ft thick. The Tawonga Fault is of interest because it was initially a dextral wrench, but Cainozoic movement, in which unconsolidated alluvials were involved, was low-angle thrusting. It is this fault which is responsible for the sharp indentation of the E. boundary of the Metamorphic Complex in the Tawonga area. The dominant fault is the West Kiewa Thrust, which forms the western boundary of the metamorphic complex. This fault was previously recorded by the writer (Beavis 1962a) as extending as far N. as Tawonga; evidence has now been obtained which extends it N. to the Yackandandah Batholith, while M. D. Leggo has found evidence of the fault from Yackandandah almost as far N. as the Murray R. It can now be stated that the entire western boundary of the Metamorphic Complex is faulted.

Discussion

Discussion of the structure may be centred on folds since all of the small-scale tectonic structures are genetically related to the folding. For the Ordovician rocks of Victoria the following generalizations can be made: folding occurs over the full distribution of the rocks, and all of the folds (with the exception of superposed structures) have a uniform trend. Any deviation from the uniform trend is localized and where changes occur, all the folds are affected. From the evidence of areas in which detailed mapping has been done, it can be stated that anticlines and synclines are equally developed and that both groups in a given area, have the same style and degree of complexity, although lithological differences may cause some modification. On the macroscopic scale there is gradation in the sediments resulting in more complex and tighter folding in the synclinoria, where pelitic beds high in the sequence are exposed, than in the anticlinoria, where predominantly arenaceous Lancefieldian and Bendigonian beds occur.

Of the small-scale structures associated with the folds, axial plane slaty cleavage is particularly informative since with only very local exceptions, throughout the sequence in the Western Trough, it has easterly dip. The axial surfaces of the folds dip easterly at 75°. This is a manifestation of the tendency to a westerly horizontal movement of the folding rock mass. Much of this information is shown on Fig. 19.

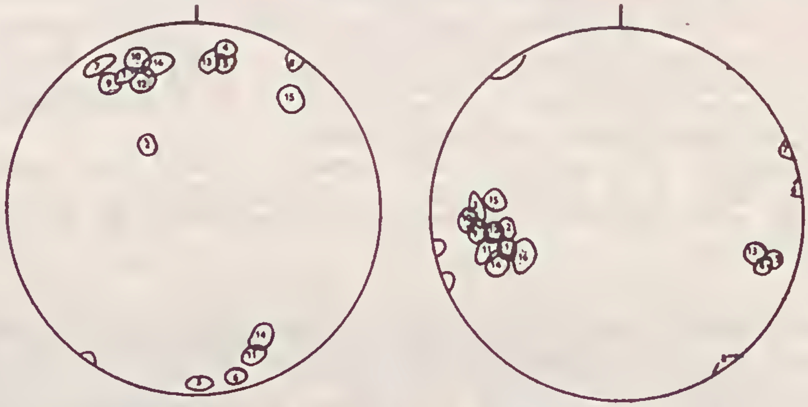

FIG. 19—Projection showing maxima of B lineations, and poles to axial surfaces, for areas of statistically cylindrical folding. Numbers signify common areas.

Consideration of individual mesoscopic folds shows almost invariably a 'similar' style, although where only sandstones are involved there may be some departures from this style. Willis & Willis (1934) introduced the concept of competent and incompetent beds in a folding sequence: incompetent beds were considered to be incapable of lifting any part of the overlying beds, while competent beds were considered to be capable of moving the passive beds and carrying up the weight of the overlying rock. Competent beds would thus transmit the stresses and form the framework of the fold. For the Ordovician rocks of Victoria, it is suggested that this concept is not valid. There has been a redistribution of material in both the slates and sandstones, manifested in a thickening of the hinges and thinning of the limbs in both sandstones and slates. While there is a difference in the degree of redistribution in the two rock types, any rock capable of flow cannot be regarded as a rigid layer which could support other rocks. Rather than relative competence controlling the style and form of folds, it seems more desirable to think of the thickness of the beds and their relative plasticity as constituting the major controls. The thin-bedded slates have formed sharper and steeper folds than either thick-bedded slates or sandstones; thin-bedded sandstones are folded more sharply than thick. In graded beds, the form of the fold seems to depend on the dominant material.

The formation of the folds is pictured here as a quite complex process in which flexure and bedding-plane slip had only minor roles. Rather, folding was the result of flow in quite plastic sediments, with a marked redistribution of material within the beds. Compression normal to the axial surface is apparent, while confining pressures tended to resist flow parallel to a, but particularly flow parallel to B. It was this resistance to flow in B which resulted in the $B \perp B'$ triclinic symmetry of the folds and the expression of this as reversal of plunge of B structures. The principle compressive stresses were E.-W., with an overall tendency to movement towards the W.

The folding seems to have commenced when the rocks were plastic and continued through to the stage when the rocks were quite brittle. In this late stage, fine scale structures, concordant with the main structures, were imposed.

The disribution of assumed and known Ordovician rocks in Victoria is clearly defined: those in Western Victoria extend from near the South Australian border to the Heathcote Axis (the Western Trough) while those of Eastern Victoria extend from Cape Howell westerly to the Dookie-Tatong Axis (the Eastern Trough). Between the Dookie-Tatong and Heathcote Axes (the Central Trough), the only occurrences of Ordovician rocks are those of the Mornington Peninsula, Enoch's Point, the Upper Goulburn and Waratah Bay, some of which may have been faulted into younger rocks. It seems clear that three separate troughs of Palaeozoic deposition existed in Victoria.

Except for a restricted occurrence of Upper Ordovician against the eastern margin of the trough, the sediments and metasediments of the Western Trough are of Lower Ordovician age (or older). In the eastern trough, with the exception of some restricted Darriwilian, the sediments and metasediments are of Upper Ordovician age. It is a reasonable hypothesis that the Western Trough ceased to exist as a basin of deposition near the close of the Lower Ordovician and that the Eastern Trough did not begin its development until very late in the Lower Ordovician. The idea also follows that the Central Trough did not exist until the end of the Upper Ordovician.

The Western Trough

As noted early in this paper, the rocks of the Western Trough may extend down into the Cambrian; certainly the most westerly of the fossiliferous sediments are Lancefieldian, and these are situated about the centre of the trough. The unfossiliferous area has associated with it restricted belts of regional metamorphism, and in places, Cambrian greenstones. It might even be considered that the crystalline schists of far Western Victoria are pre-Cambrian basement.

In any case, it is postulated that the Western Trough began its development in far W. Victoria and advanced towards the E. during the Lower Ordovician. By Lancefieldian times, the trough extended laterally from the Heathcote Axis as far W. as Maryborough, but later, in post-Chewtonian times, it was restricted to a narrow, easterly advancing trough, confined between the Muckleford Fault and the Heathcote Axis. At no time was deposition occurring simultaneously over the present width of distribution of the Ordovician rocks. Folding and faulting played an intimate role in the easterly progression of the trough and folding is considered to have occurred concurrently with deposition. Further work to assess variation in sorting, thickness and the existence of minor disconformities is essential to test fully this hypothesis.

Metamorphic rocks occur only in the western half of the trough and are usually associated with granitic intrusions. The metamorphism is not, however, a local contact type, but there is strong evidence of regional metamorphism with transposition on penetrative foliations and lithological layering due to metamorphic differentiation. Little is yet known of these metamorphic rocks, but some, at least, may represent deep burial on structural lows just as greenstones are exposed on structural highs.

There is some evidence from Stawell, Mostyn and Charlton that the metamorphic rocks have small folds superposed on the main structures, but this does not appear to be general, and in fact, throughout the Western Trough it is clear that the rocks have suffered only a single regional folding. The only superposed folding is quite local: Stawell, Mostyn, Charlton, Maryborough, Harcourt and Anakie where later faulting and forced intrusion have occurred.

The structural evidence of a more or less uniform style throughout the Western Trough suggests a uniform stressing. If the hypothesis of an advancing basin is valid, then a more or less continuous folding throughout the Lower Ordovician must be accepted.

The Central Trough

In the Mornington Peninsula there is an almost complete sequence of Ordovician rocks through from Lancefieldian to Bolindian, the total thickness exceeding 15,000 ft. Elsewhere in the Central Trough the exposed Ordovician rocks are of Darriwilian or Upper Ordovician ages. The Mornington sequence suggests deposition in a small isolated basin. Elsewhere in the Central Trough, it may be that no Ordovician deposition occurred. It is known that the trough is occupied by an immense thickness of Silurian and Devonian sediments. The possibility that sediments are underlain by Ordovician rocks cannot be excluded.

The Eastern Trough

Graptolites from high in the Lower Ordovician have been recorded from Myrtleford and Gibbo; all other graptolites recorded from this trough are Upper Ordovician forms. This virtual absence of Lower Ordovician suggests that the trough did not develop until very late in the Lower Ordovician.

It is generally accepted that the trough broke up in the epi-Ordovician Benambran orogeny, with small isolated basins of deposition persisting until mid-Devonian times. This trough, like the Western Trough, can be regarded as one of short duration. Its dimensions are similar to those of the Western Trough and the structures are comparable. It is not possible, with a complete absence of stratigraphic data, to determine the history of the trough, other than in outline. It is quite clear, however, that there was a regional superposition of second generation folds and cleavages and a local superposition of third generation structures.

Conclusions

It is postulated that two major troughs of deposition and deformation developed during the Ordovician in Victoria. The Western Trough began its development in far Western Victoria, possibly in Cambrian times, and advanced easterly, reaching its maximum development early in the Lower Ordovician and virtually ceasing to exist in the Upper Ordovician. Deposition and deformation were almost contemporaneous. The Eastern Trough did not begin its development until very late in the Lower Ordovician and broke up at the end of the Upper Ordovician. Between these two troughs was the Central Trough in which only small isolated Ordovician deposition occurred. Its main development was in the Silurian and Devonian.

The style of structures in the Eastern and Western Troughs is the same, but regional superposition of second generation structures, typical for the Eastern Trough, has not occurred in the Western Trough. There is no evidence in the Eastern Trough to show whether folding was continuous and contemporaneous with deposition as there is for the Western Trough.

References

BARAGWANATH, W., 1917. The Ballarat Goldfield. *Geol. Surv. Vict. Mem.* 14, pp. 1-257, 32 Pl., 65 Figs.

BEAVIS, F. C., 1960. The Tawonga Fault, North East Victoria. *Proc. Roy. Soc. Vict.* 72: 95-100.

———, 1962a. The Geology of the Kiewa Area. *Ibid.* 75: 349-412.

———, 1962b. Contact metamorphism at Big Hill, Bendigo. *Ibid.* 75: 89-100.

———, 1963. Superposed Folding in the North East Victorian Metamorphic Complex. *Aust. J. Sci.* 26: 23-24.

———, 1964a. Strain Slip Cleavage in Ordovician Sediments of Central Victoria. *Geol. Mag.* 101: 504-511.

———, 1964b. The structural analysis of the Harcourt Batholith Contact Aureole. *Proc. Roy. Soc. Vict.* 77: 149-175.

———, 1964c. Superposed folding in the Beechworth Contact Aureole. *Ibid.* 77: 265-272.

———, 1965a. Strain slip foliation in low grade Metamorphic rocks. *Ibid.* 78: 75-84.

——— & BEAVIS, JOAN H. The structural geology of the Ordovician rocks, Steiglitz. (In prep.)

CALDWELL, J. J., 1931. Eppalock. *Geol. Col. Par. Plan. Geol. Surv. Vict.*

CLAPPISON, R. J. H., 1960. The relationship of structure and ore deposition at Stawell Goldfield. *Proc. Aust. Inst. Min. Met.* 195: 1-10.

CLOOS, E., 1964. Lineation. *Geol. Soc. America Mem.* 18.

CROHN, P. W., 1949. Geology of the Omeo District. *Proc. Roy. Soc. Vict.* 62: 1-70.

FERGUSON, W. H., 1940. The Steiglitz Goldfield. *Geol. Map. Geol. Surv. Vict.*

FERMOR, L. L., 1909. The manganese ore deposits of India. *Mem. Geol. Surv. India*, xxxvii, pp. i-xcvii, 1-1294.

FOURMARIER, P., 1949. Etirement des roches et la Schistosité. *Bull. Soc. Géol. France*, Ve Série, 19: 569-574.

———, 1953. Schistosité et Phénomènes Comènes dans les séries Plissées. *Congr. Geol. Int. Alger*, Sect. 2: 117-132.

HARRIS, W. J., 1933. The eastern boundary of the Bendigo Goldfield. *Proc. Roy. Soc. Vict.* 46: 200-206.

——— & CRAWFORD, W., 1921. The relationships of the sedimentary rocks of the Gisborne District, Victoria. *Ibid.* 33: 39-78.

——— & THOMAS, D. E., 1934. Geological structure of the Lower Ordovician rocks of East Talbot. *Ibid.* 46: 153-178.

——— & ———, 1948. The geology of Campbelltown. *Min. Geol. J. Vict.* 3 (3): 46-54.

——— & ———, 1949. Geology of the Meredith Area. *Ibid.* 3 (5): 43-61.

HILLS, E. S., 1955. *Outlines of Structural Geology*. Methuen, London.

———, 1963. *Elements of Structural Geology*. Methuen, London.

——— & THOMAS, D. E., 1944. Deformation of Graptolites. *Geol. Mag.* 81: 216-222.

——— & ———, 1945. Fissuring in sandstones. *Econ. Geol.* 40: 51-62.

——— & ———, 1953. Turbidity currents and the graptolites facies in Victoria. *J. Geol. Soc. Aust.* 1: 119-133.

HOEPPENER, R., 1956. Zum problem der Bruchbildung, Schieferung, und Faltung. *Geol. Rundsch.* 45: 247-283.

KENNY, J. L. P., 1937. Damsites at Mitta Mitta. *Rec. Geol. Surv. Vict.* 5: 467.

KNILL, J. L., 1960. A classification of cleavage. *Int. Geol. Congr.* 21st Sess., 18: 317-325.

LEGGO, M. D., 1965. Geology of the Beechworth District. *University of Melbourne, unpublished M.Sc. Thesis.*

LEITH, C. K., 1905. Rock cleavage. *U.S. Geol. Surv. Bull.* 239.

———, 1923. *Structural Geology*. Holt & Co, New York.

MAXWELL, J. C., 1962. Origin of slaty and fracture cleavage in the Delaware Water Gap Area. *Petrologic Studies, Buddington Volume Geol. Soc. America*: 281-311.

MUGGE, O., 1930. Bewegungen von porphyroblasten in Phylliten und ihre Messung. *N. Jb. Miner.*, BB.61 A: 469-510.

Pilger, A., & Schmidt, W., 1957a. Definition des Begriffes 'Mullion Struktur'. *N. Jb. Geol. Paläont. Mh.*: 24-28.

——— & ———, 1957b. Die Mullion Strukturen in der Nord-Eifel. *Abh. Hess. L.A. Bodenforsch. zu Wiesbaden* 20: 1-53.

Ramsay, J. G., 1962. The geometry and mechanics of formation of 'similar' type folds. *J. Geol.* 70: 309-327.

Rickard, R. J., 1961. A note on cleavages in crenulated rocks. *Geol. Mag.* 99: 516-526.

Sharpe, D., 1847. On slaty cleavage. *Quart. J. Geol. Soc. Lond.* 3: 47.

Sorby, H. C., 1853. On the origin of slaty cleavage. *Edin. New. Phil. J.* 55: 137.

Tattam, C. M., 1929. The metamorphic rocks of North East Victoria. *Geol. Surv. Vict. Bull.* 52.

Thomas, D. E., 1932. The Kerrie series and associated rocks. *Proc. Roy. Soc. Vict.* 44: 257-288.

———, 1935. The Muckleford Fault in the Guilford-Strangways Area. *Ibid.* 47: 213-224.

———, 1939. The structure of Victoria with respect to the Lower Palaeozoic rocks. *Min. Geol. J. Vict.* 1 (4): 59-64.

Turner, F. J. & Weiss, L. E., 1963. *Structural Analysis of Metamorphic Tectonites.* McGraw-Hill, New York.

Weiss, L. E. & McIntyre, D., 1957. Structural geometry of Daldradian rocks at Loch Leven. *J. Geol.* 65: 575-601.

Wells, B. E., 1956. Geology of the Casterton District. *Proc. Roy. Soc. Vict.* 68: 85-110.

Willis, B. & Willis, R., 1934. *Geologic Structure.* McGraw-Hill, New York.

Wilson, G., 1953. Mullion and Rodding structures in the Moine series of Scotland. *Proc. Geol. Assoc. Lond.* 64: 118.

———, 1961. The tectonic significance of small scale structures. *Ann. Soc. géol. Belg.* 84: 424-548.

Wood, B. L., 1963. Structure of the Otago Schists. *N.Z. J. Geol. Geophys.* 6: 641-680.

Explanation of Plates

Plate 23

Fig. 1—Strain slip cleavage in sandstone, Steiglitz, showing conjugate pattern.
Fig. 2—Cuspate structure at base of sandstone, Hanover Fault, Steiglitz.

Plate 24

Fig. 1—Lozenge structure in sandstone, Anakie.
Fig. 2—Fine crenulations on strain slip cleavage in sandstone, Meredith.

Plate 25

Fig. 1—Ripple lineation in silicified slate, Steiglitz.
Fig. 2—Coarse ripple lineation in sandstone, Woodend.

Plate 26

Fig. 1—Change in plunge of fold, Calder Highway, Macedon.
Fig. 2—Folding in fine sandstones, siltstones and slates, Morrisons.

Plate 27

Fig. 1—Mesoscopic F_1 fold in phyllite, Mt. St. Bernard.
Fig. 2—Mesoscopic F_2 fold in phyllite, Mt. Feathertop. This fold is the type Feathertop Style. (× 2.)

Plate 28

Fig. 1—Mesoscopic F_2 (Snowy Creek Style) fold in phyllite, Snowy Ck. West, Mitta Mitta. (× $\frac{1}{8}$.)
Fig. 2—Mesoscopic F_2 (Tawonga Style) fold in chlorite-quartz-albite schist, Symmonds Ck., Tawonga South. (× $\frac{1}{2}$.)
Fig. 3—Lineations L_2 in S_1, with F_3 conjugate structures in upper left, Granite Flat.

Plate 29

Fig. 1—Mesoscopic F_3 (Harrietville Style) fold in phyllite, Omeo Highway, Mitta Mitta. (× $\frac{1}{10}$.)
Fig. 2—Mesoscopic F_3 (Blowhard Style) fold in metagreywacke, Snowy Ck.

Plate 30

Mesoscopic F_3 (Hotham Style) folds in S_1 of phyllite, Mt. Blowhard. Note the three generations of lineations present in S_1. (× 1.)